

Light and Shading

EECS 442 – Jeong Joon Park
Winter 2024, University of Michigan

<http://eeecs442.github.io>

Administrivia

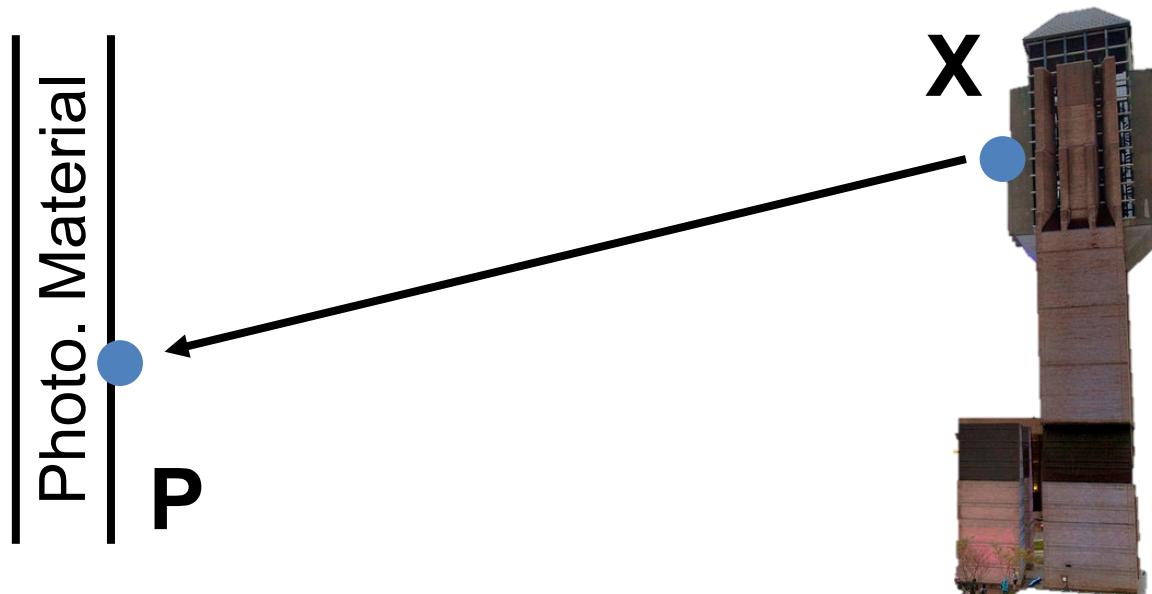
- HW1 Due in a Week
- Please sign up for Piazza
- Piazza highlights:
 - student answers (please pay it forward!)
 - Would be great if you can participate in discussions!
 - TAs are very hard-working! Constantly on Piazza.
- Collaborations:
 - How many of you have found study mates?
 - Highly encourage posting and participating to study buddy search on Piazza -- 16 groups so far

Thoughts on Homework

- Some self-study will be required for:
 - Reinforcing concepts
 - Learning libraries (there's great documentation!)
 - Often “self-study” parts won't be indicated
- Try first aid tips for debugging
 - Print X.shape, X.dtype, X when you're stuck
 - plt.imsave("debug.png",X)
 - Read documentation
- This is a skill you need if you're going to do rewarding programming

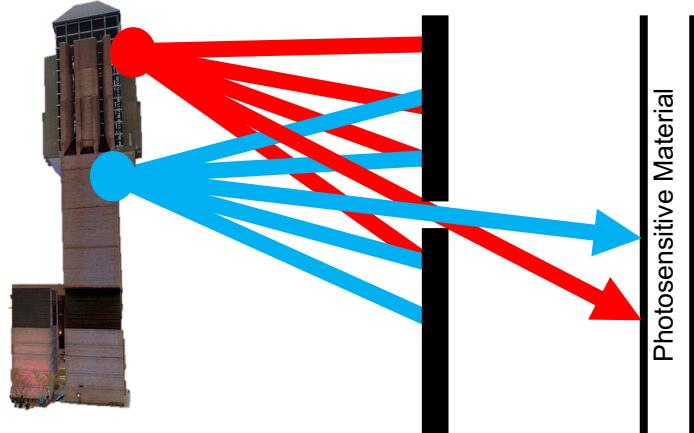
Recap: Projection

$$\text{Image} \rightarrow P = K[R, t]X \leftarrow \begin{matrix} \text{World} \\ \text{Intrinsic} \quad \text{Extrinsic} \end{matrix}$$



Recap: Lenses

Pinhole Model



Mathematically correct
Not quite correct in practice
Reasonable approximation

Reality: Lenses

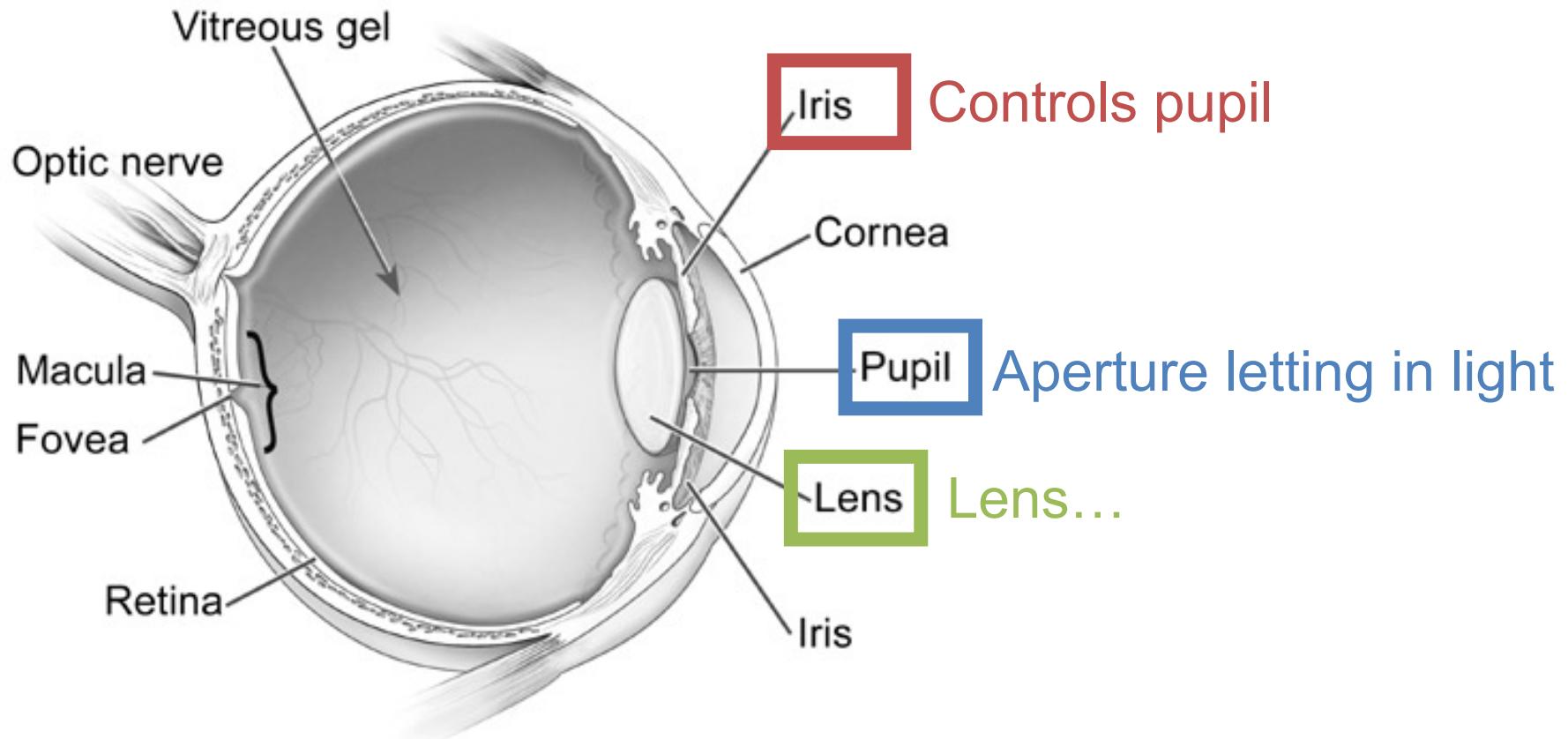


Necessary in practice
Introduce complications
Complications fixable

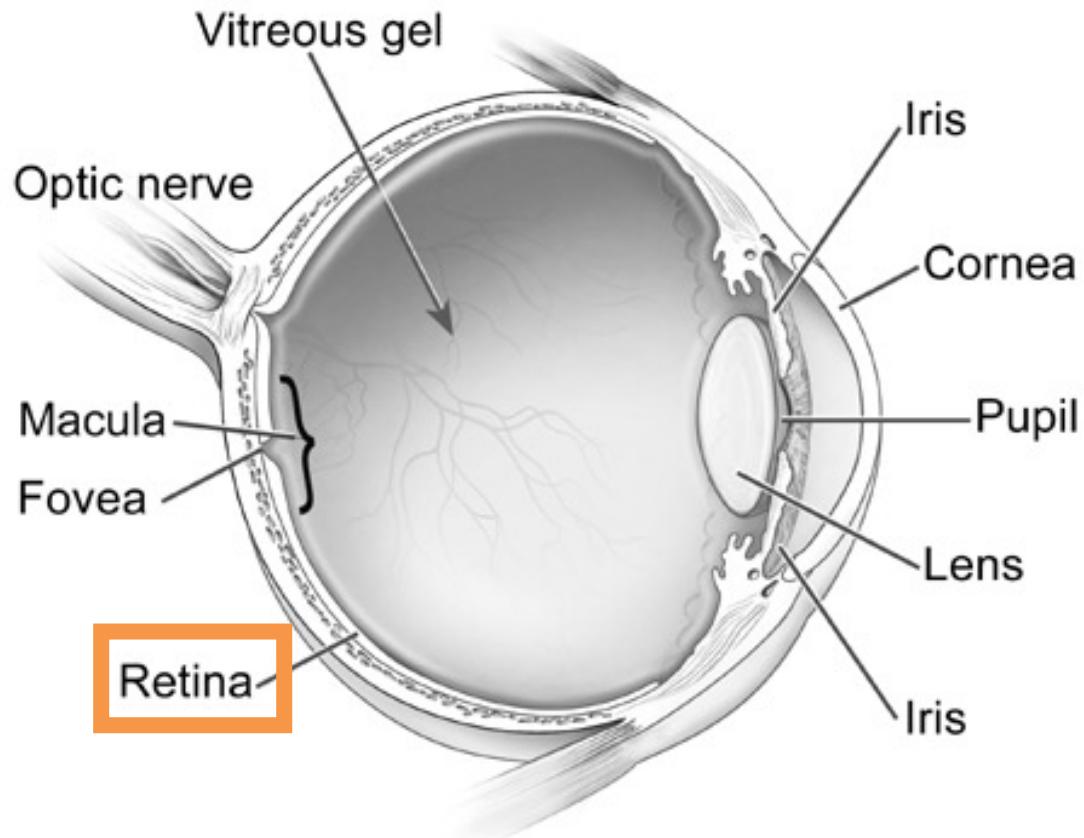
Today

- A little bit about light and how you represent it
- A little bit about lighting and how it works

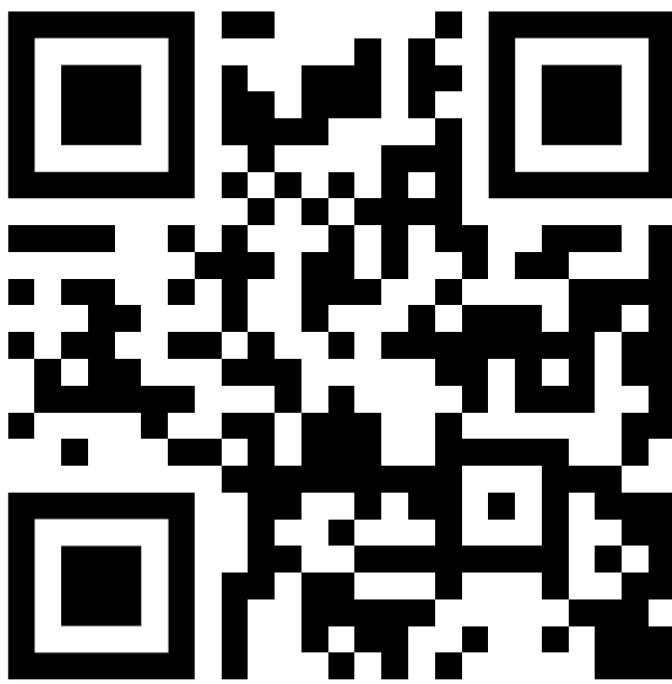
Your Very Own Camera



Your Very Own Camera

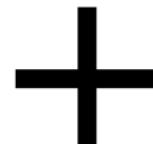


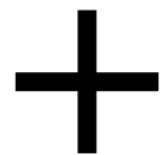
Where's the **film/CCD?**



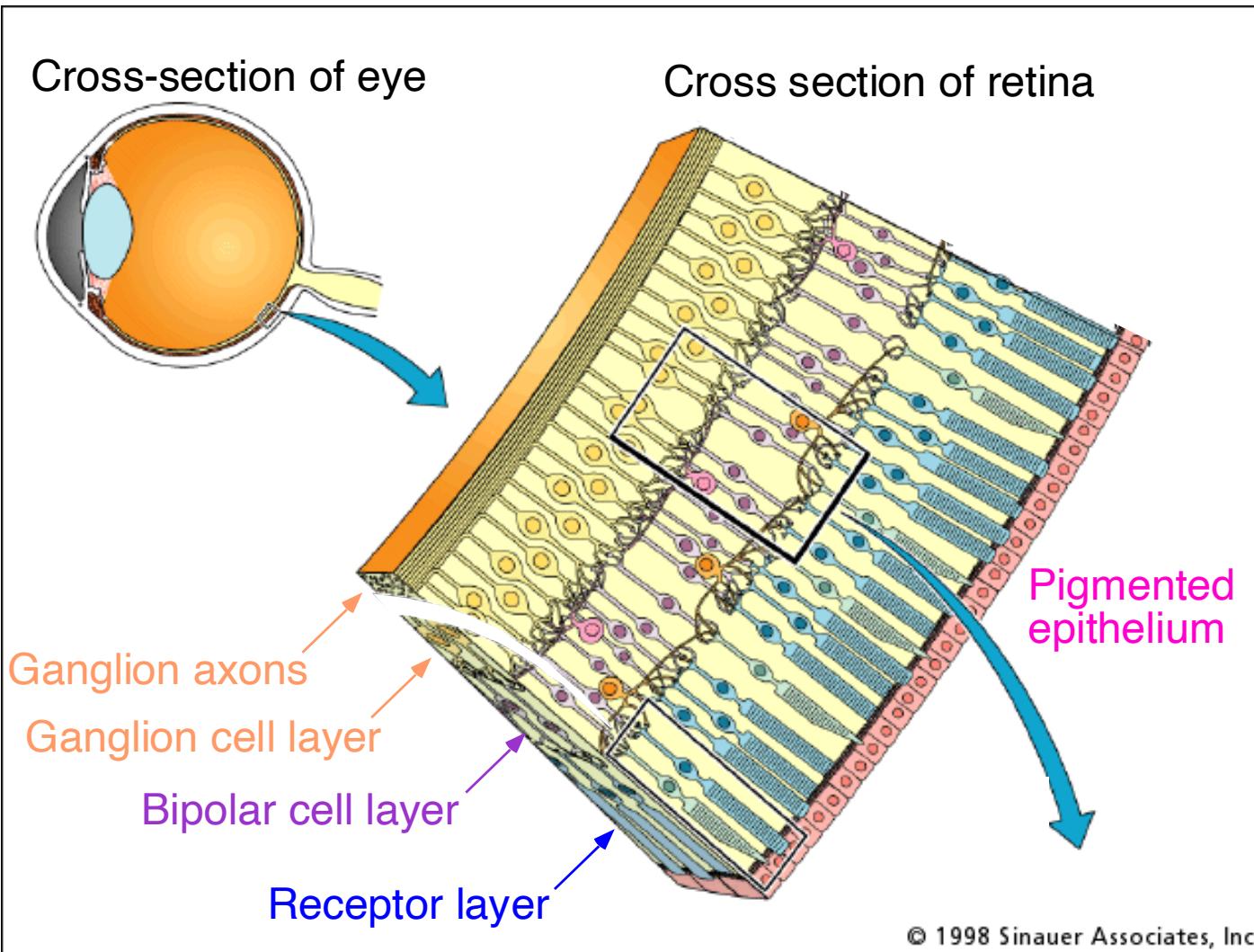
Demo Time

[https://tinyurl.
com/442w23](https://tinyurl.com/442w23)





What is Retina/Film Made Of?



© 1998 Sinauer Associates, Inc.

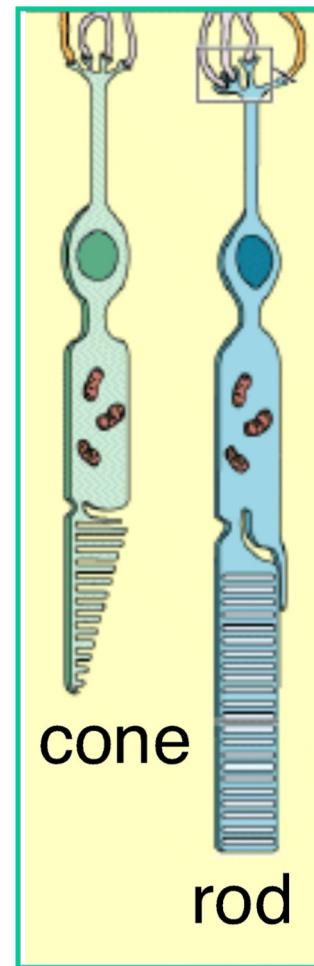
Two Type of Photo Receptors

Cones

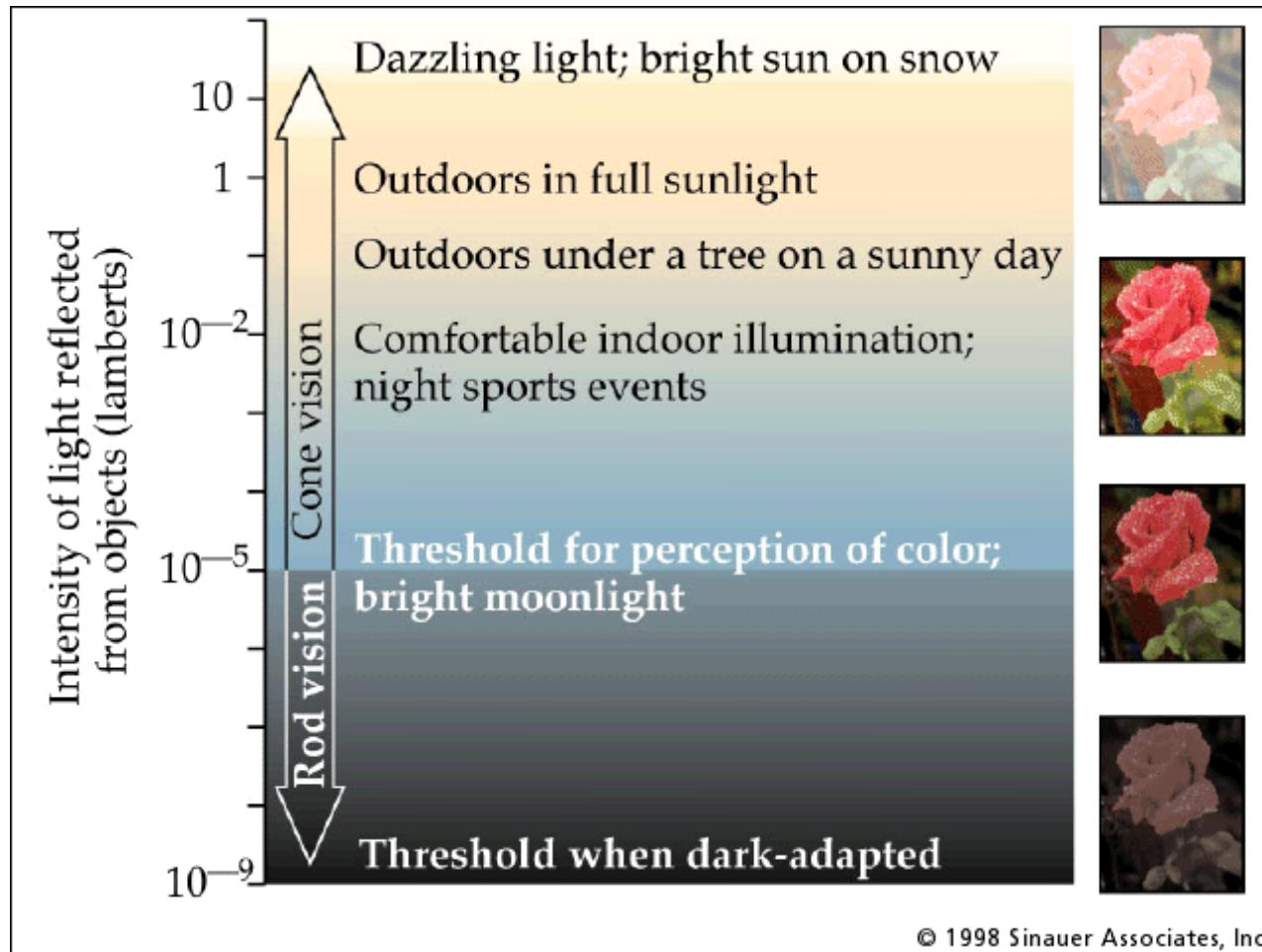
cone-shaped
less sensitive
operate in high light
color vision

Rods

rod-shaped
highly sensitive
operate at night
gray-scale vision



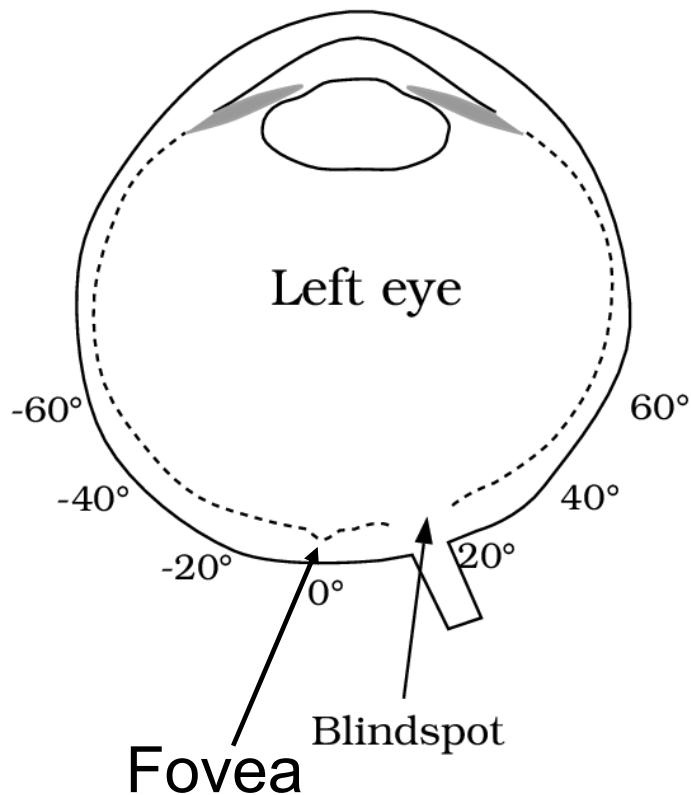
Rod / Cone Sensitivity



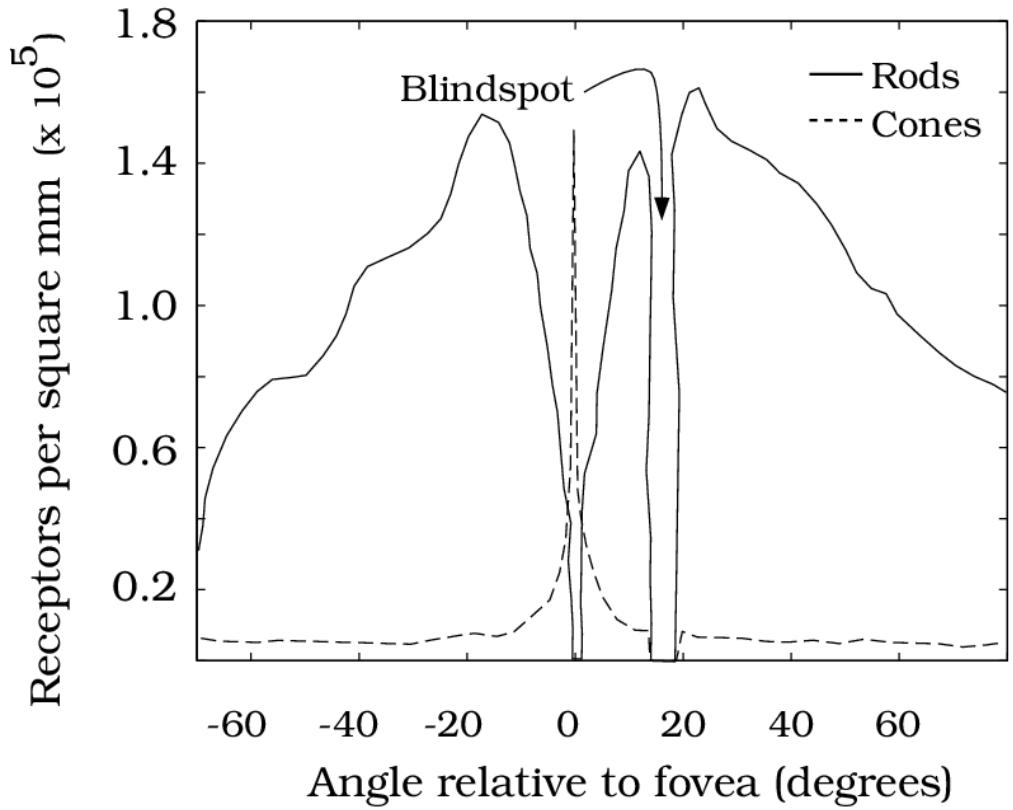
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Rod/Cone Distribution

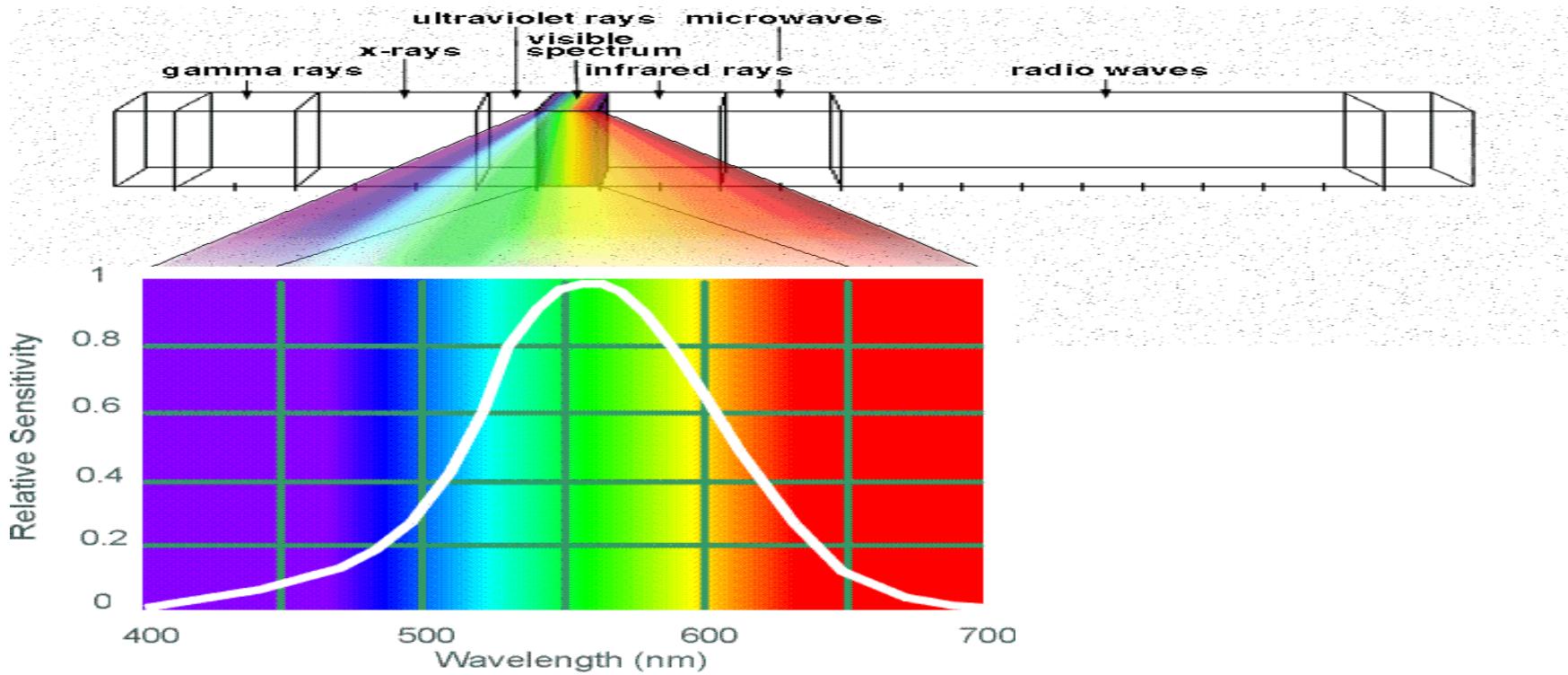
(a)



(b)

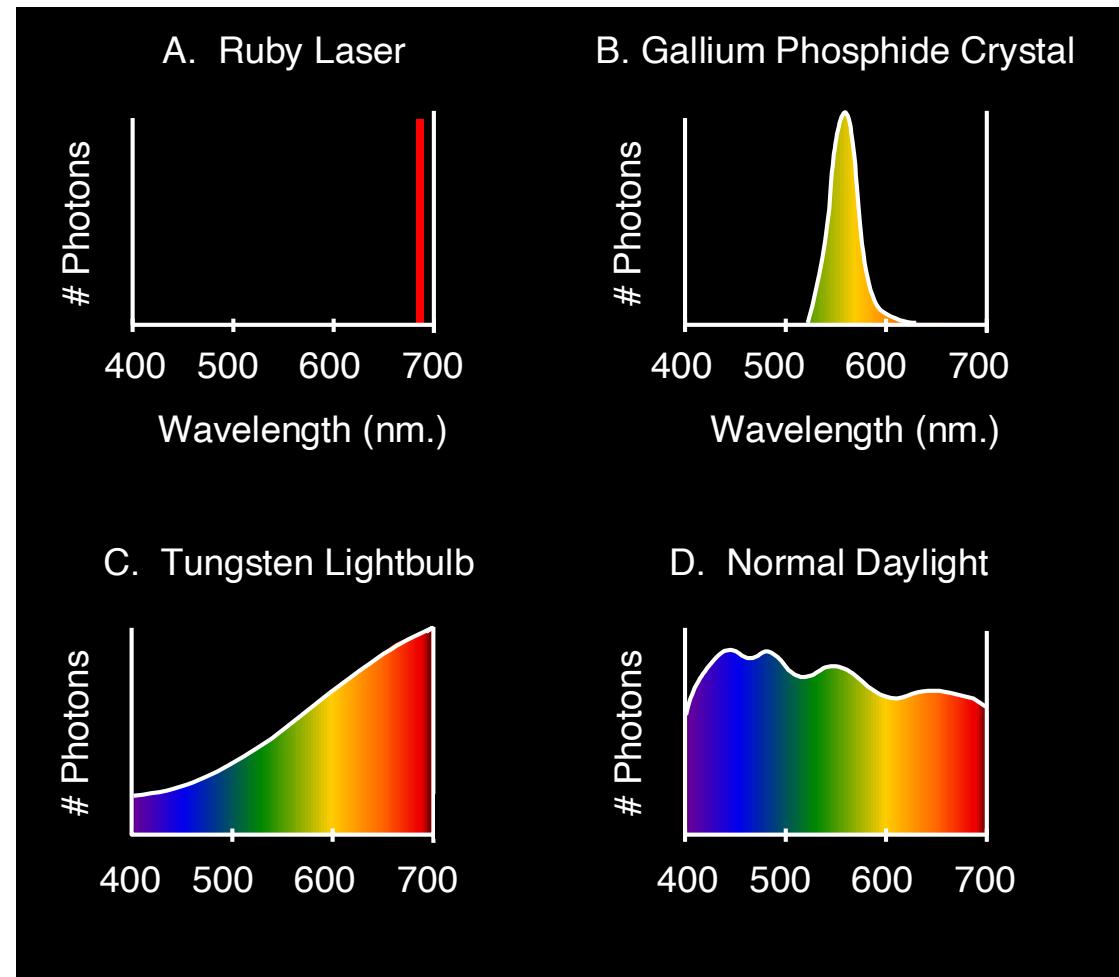


Electromagnetic Spectrum

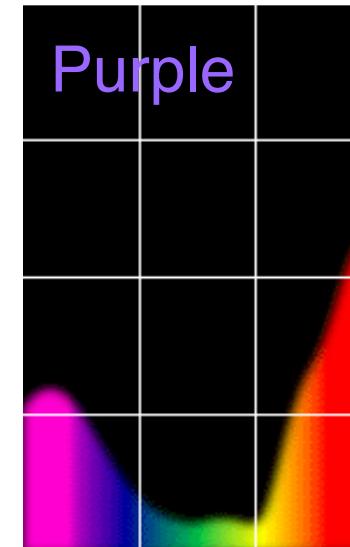
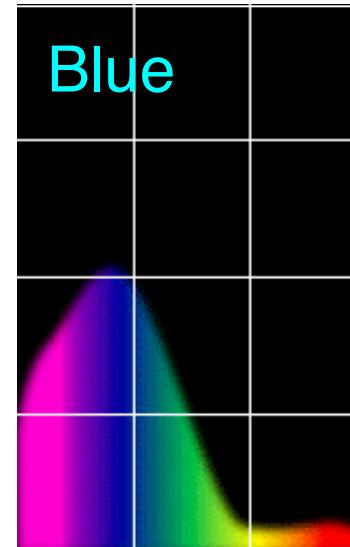
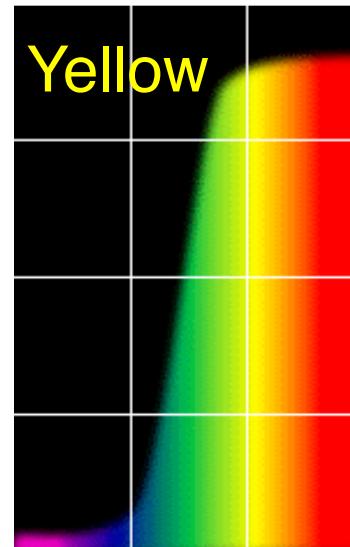
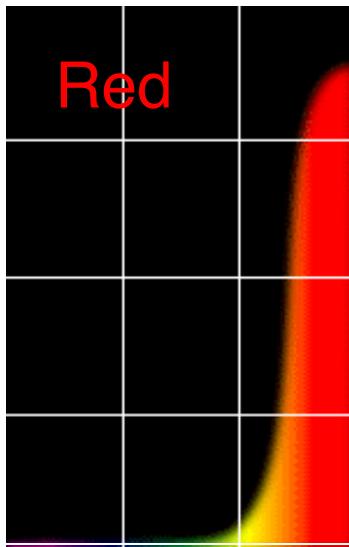


Why do we see light in these wavelengths?

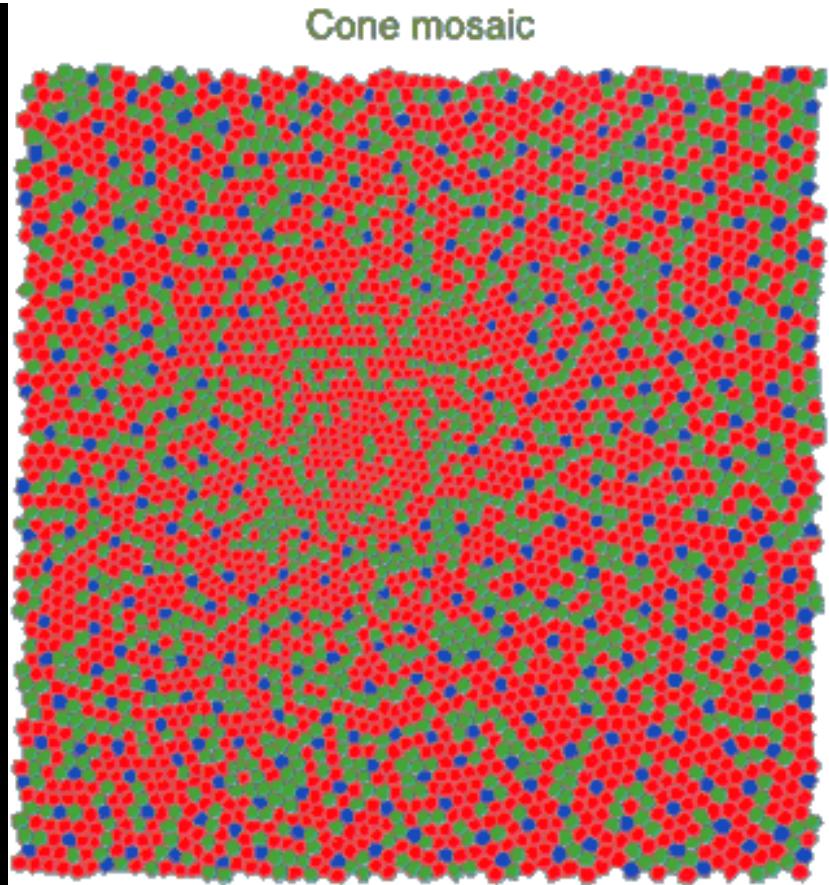
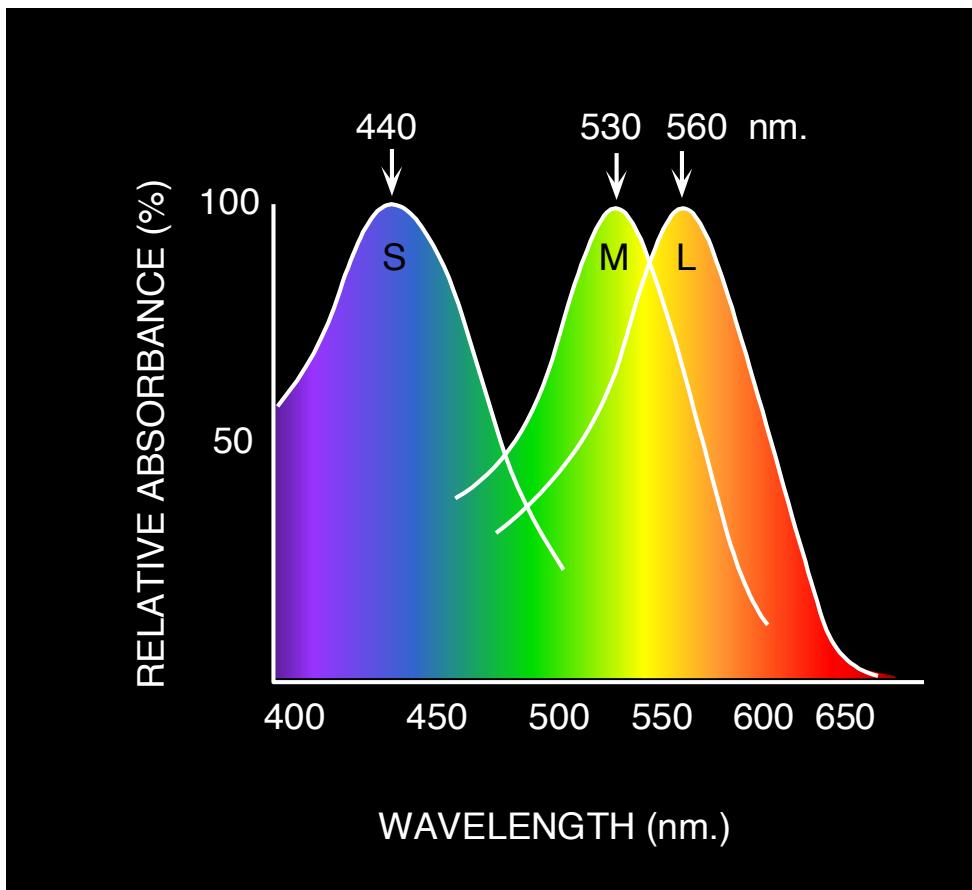
The Physics of Light



The Physics of Light

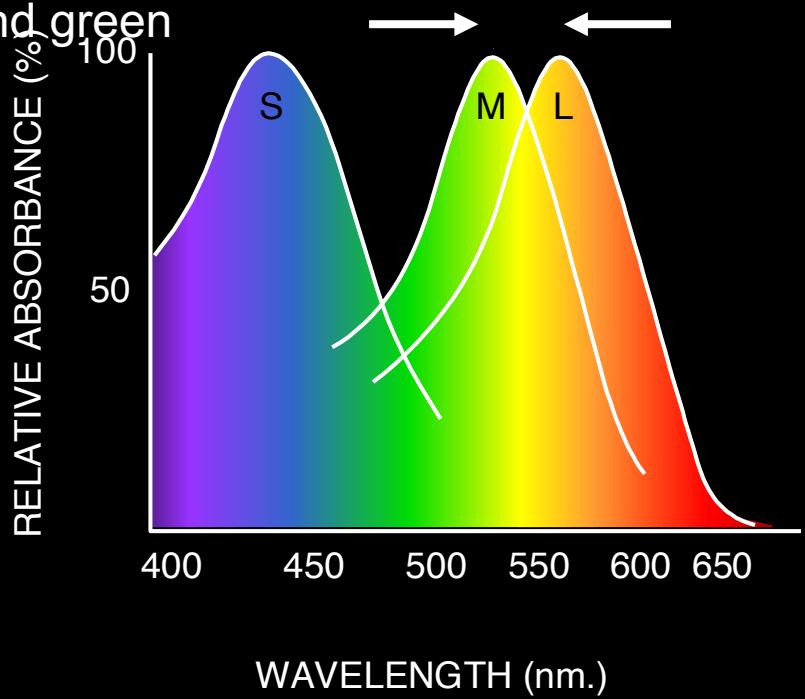


The Physics of Light



Red-Green Color Blindness

"Peaks" of these red/green cones shifted, making it hard to distinguish red and green



Four possibilities:

- **Deuteranomaly:** Green cone shifted toward red
- **Protanomaly:** Red cone shifted toward green
- **Deuteranopia:** Green cone missing
- **Protanopia:** Red cone missing

Color Vision in Animals

Birds have 4 cone types:
can see ultraviolet light

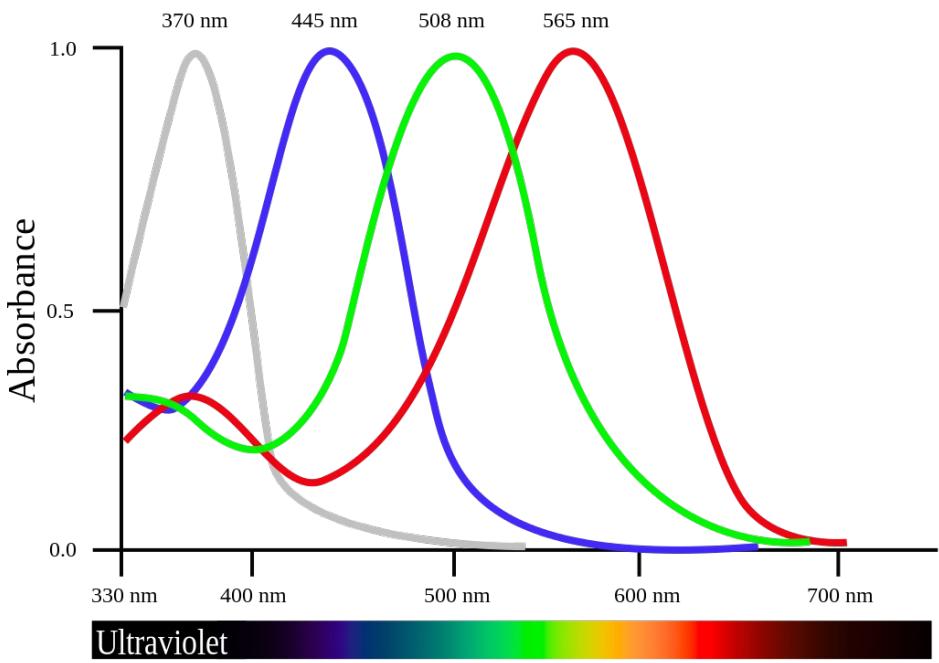


Image source: [Wikipedia](#)

Some flowers have
“Nectar Guides” in UV

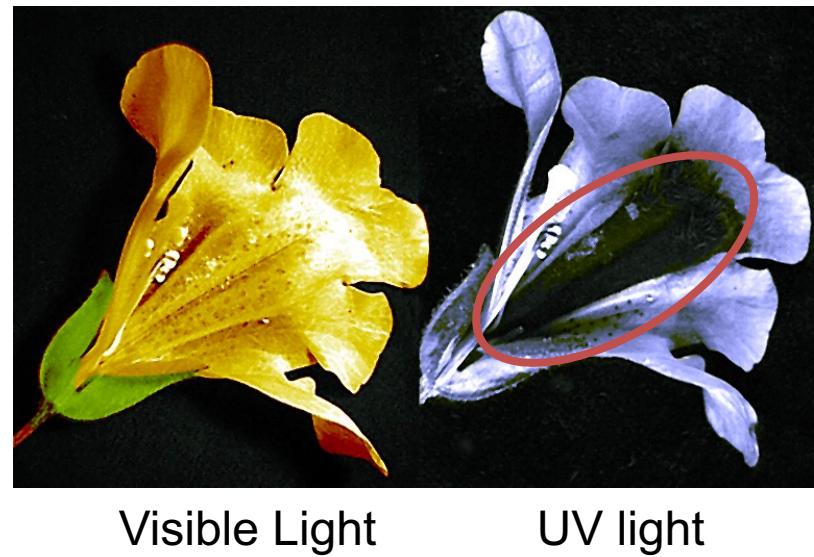


Image Source: [Wikipedia](#)

JANUARY 11, 2022 | ARTS & CULTURE

Could Claude Monet See Like a Bee?

A harrowing eye surgery may have given the impressionist painter the ability to see UV light.

by [Sam Kean](#)

Detail, *Water Lilies (Nymphéas)*, Claude Monet, ca. 1915–1926.

Carnegie Museum of Art/Wikimedia Commons



Color Vision in Animals

Mantis Shrimp: Up to 16 types of photoreceptors!
Can also detect polarization of light!

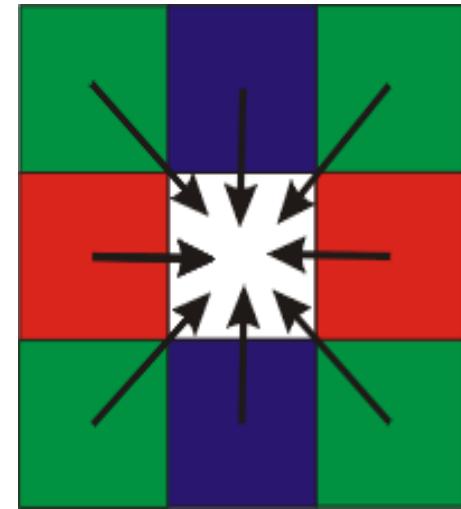
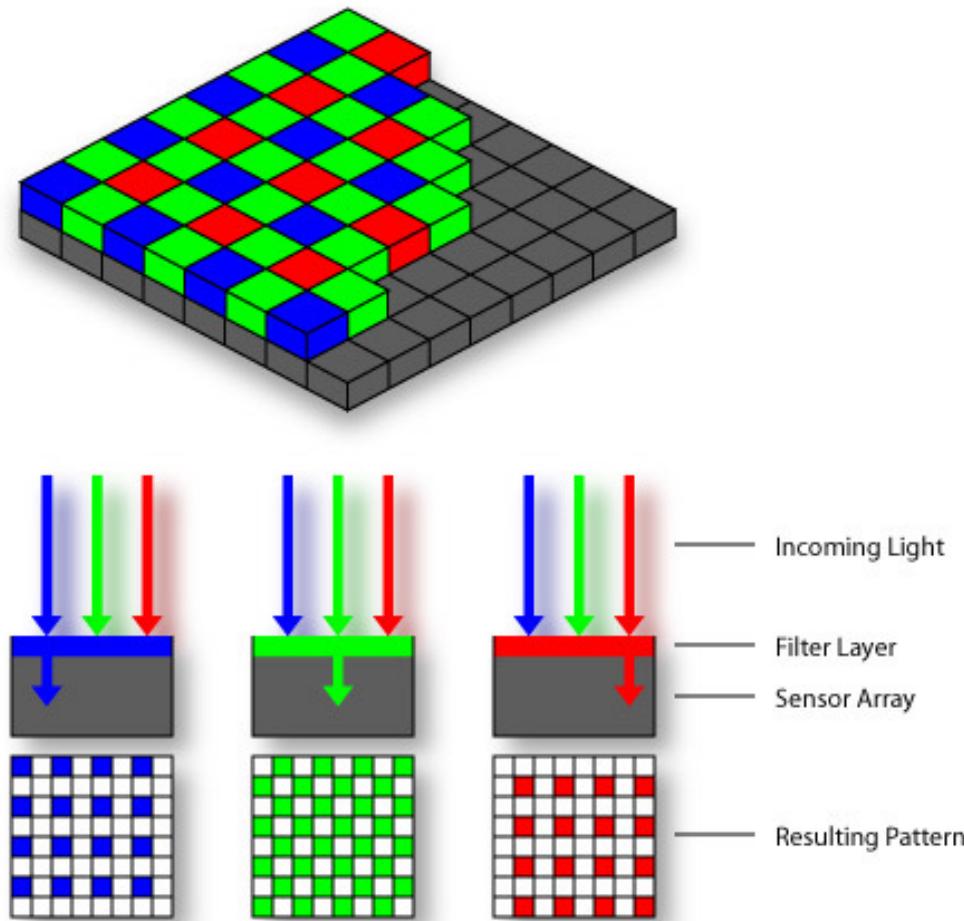


Image source: [Wikipedia](#)

How Do We Get Light?

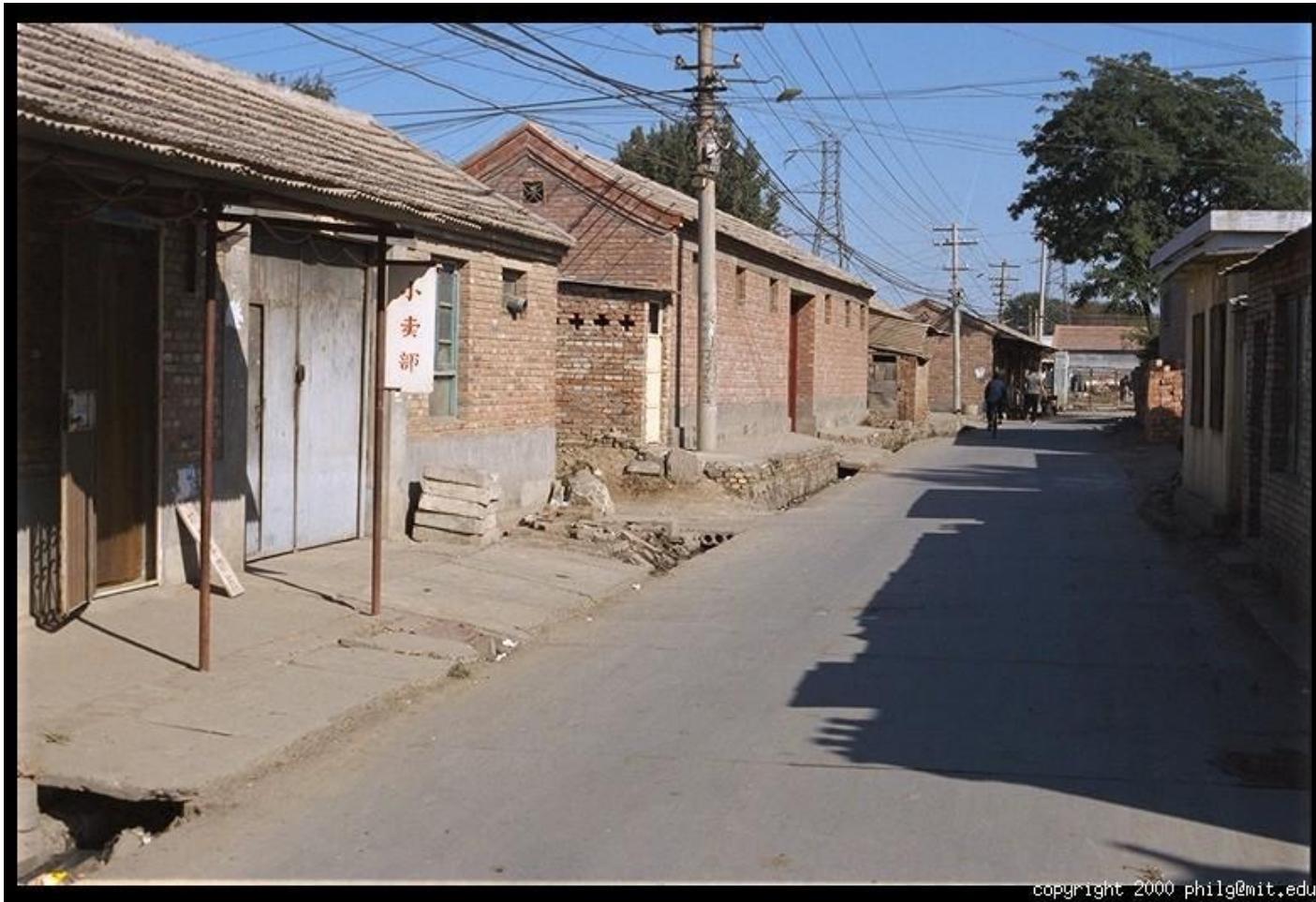
- Cameras!

Artificial Cones



Estimate RGB
at 'G' cells from
neighboring
values

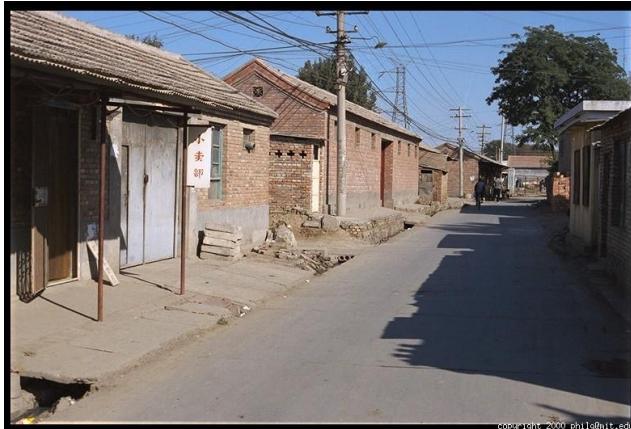
Color Image



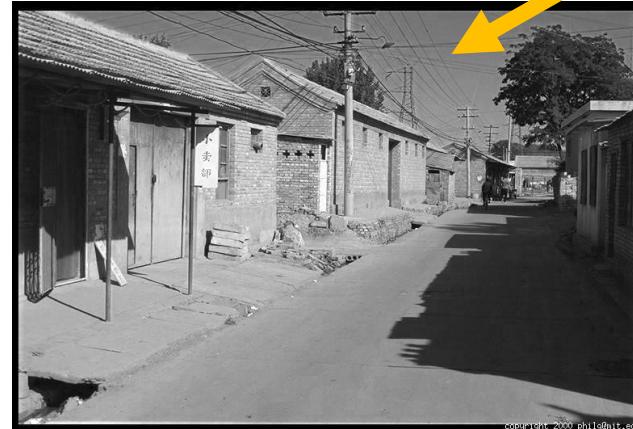
copyright 2000 philg@mit.edu

Color Image

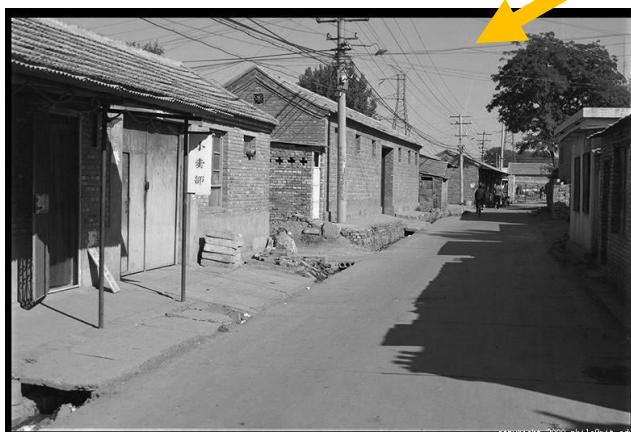
Combined



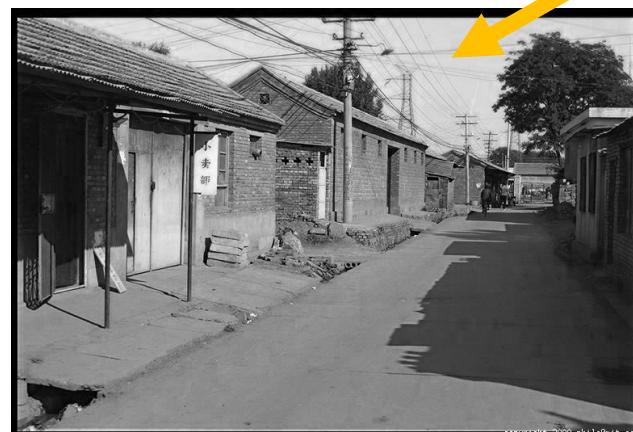
Red



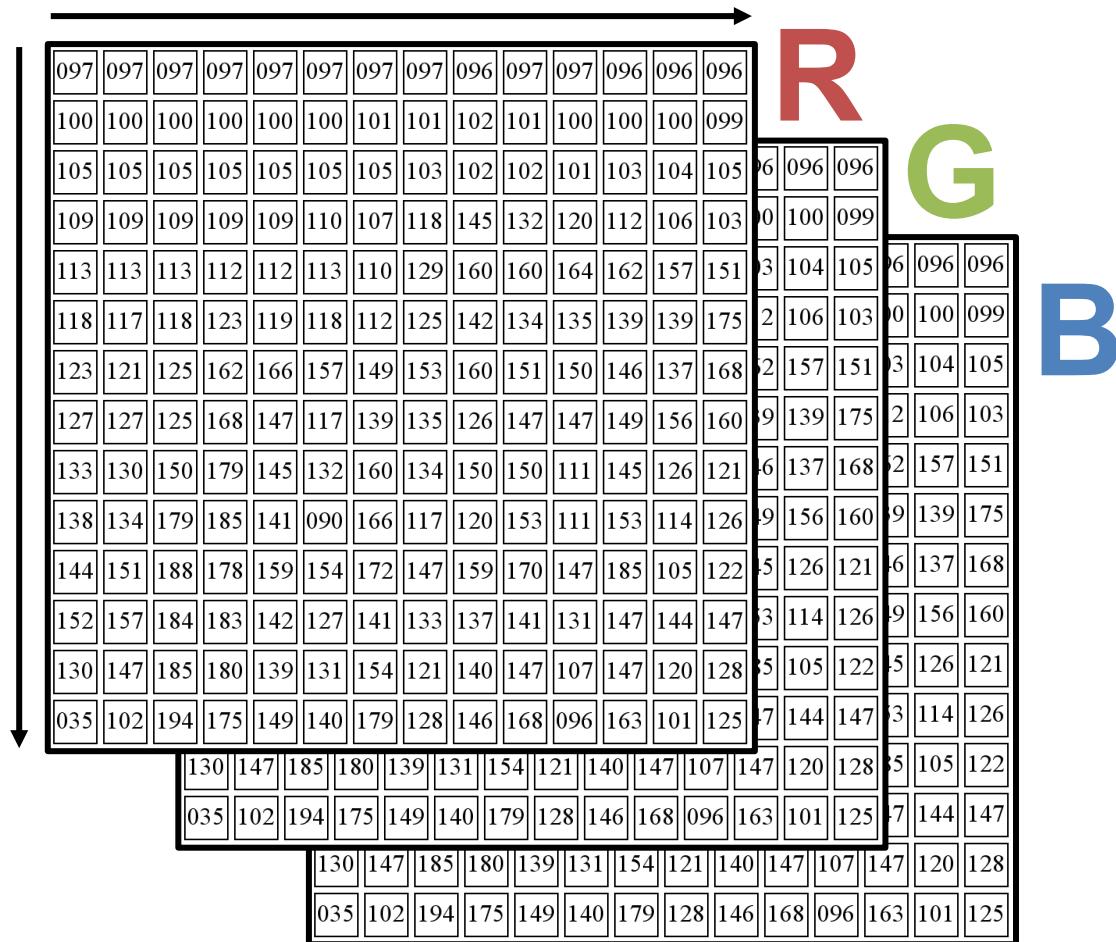
Green



Blue



Images in Python



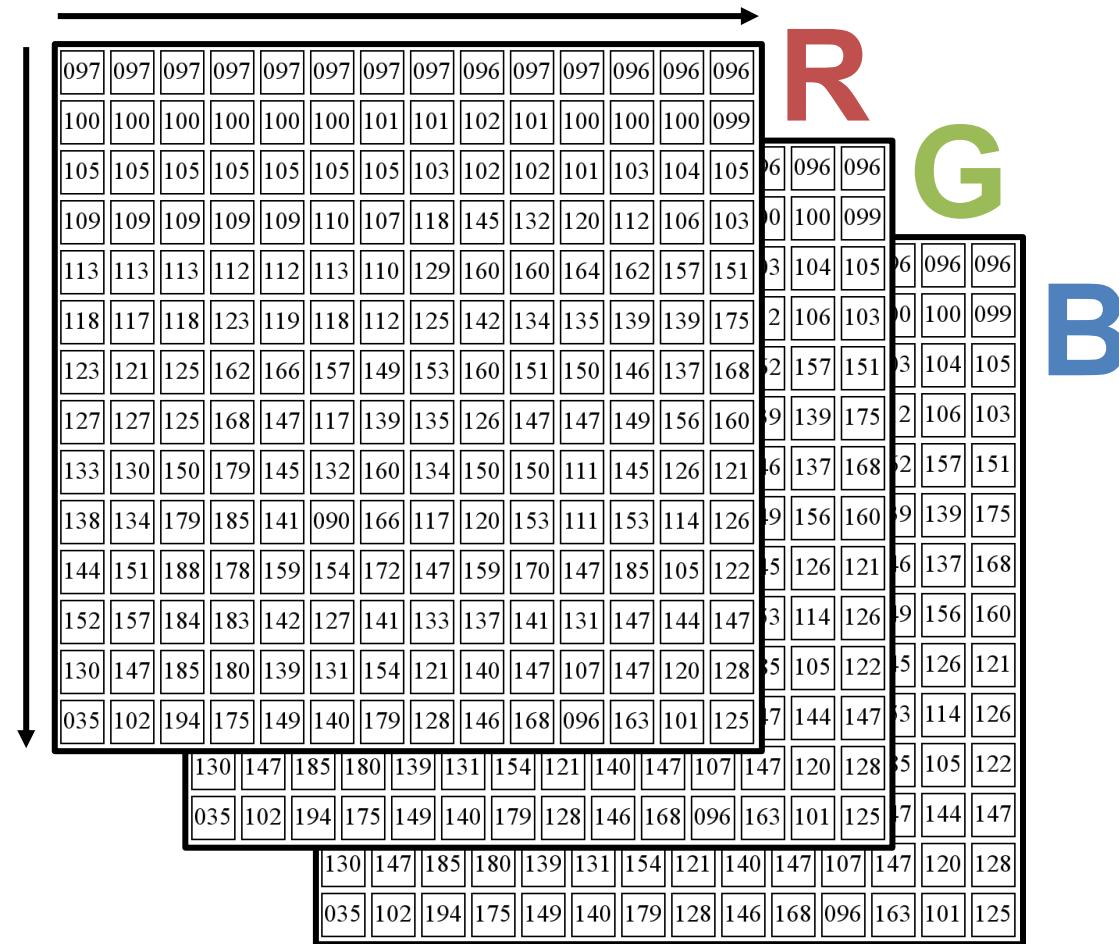
Images in Python

Images are matrix / tensor im

im[0,0,0]
top, left, red

im[y,x,c]
row y, column x, channel c

im[H-1,W-1,2]
bottom right blue



Images in Python

Images are matrix

`im[0,0,0]`
top, left,

`im[y,x,c]`
row y, column x, ch.

`im[H-1,W-1,2]`
bottom right blue

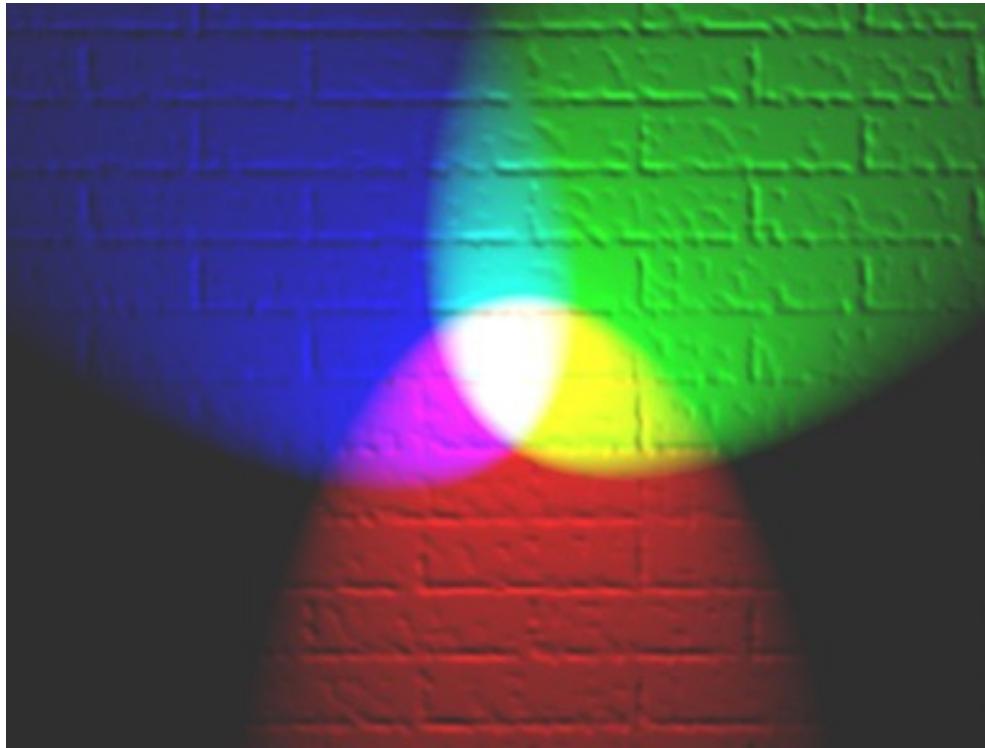
ARGH!

I	B	G	R
097	097	097	097
100	100	100	100
105	105	105	105
109	110	107	118
110	105	105	145
112	102	102	132
114	101	101	120
116	103	103	112
118	104	104	106
120	105	105	103
122	103	103	103
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126	105	105	105
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748	416	416	416
750	417	417	41

5 Things To Remember

1. Origin is top left
2. Rows are first index (**what's the fastest direction for accessing?**)
3. Usually referred to as Height x Width
4. Typically stored as uint8 [0,255]
5. for y in range(H): for x in range(W): will run 1 million times for a 1000x1000 image. A 4GHz processor can do only 4K clock cycles per pixel per second.
6. *In PyTorch: Channel x Height x Width*

Representing Colored Light



Discussion time: how many numbers do you actually need for colored light? Assume all tuples (R,G,B) are legitimate colors (they are).

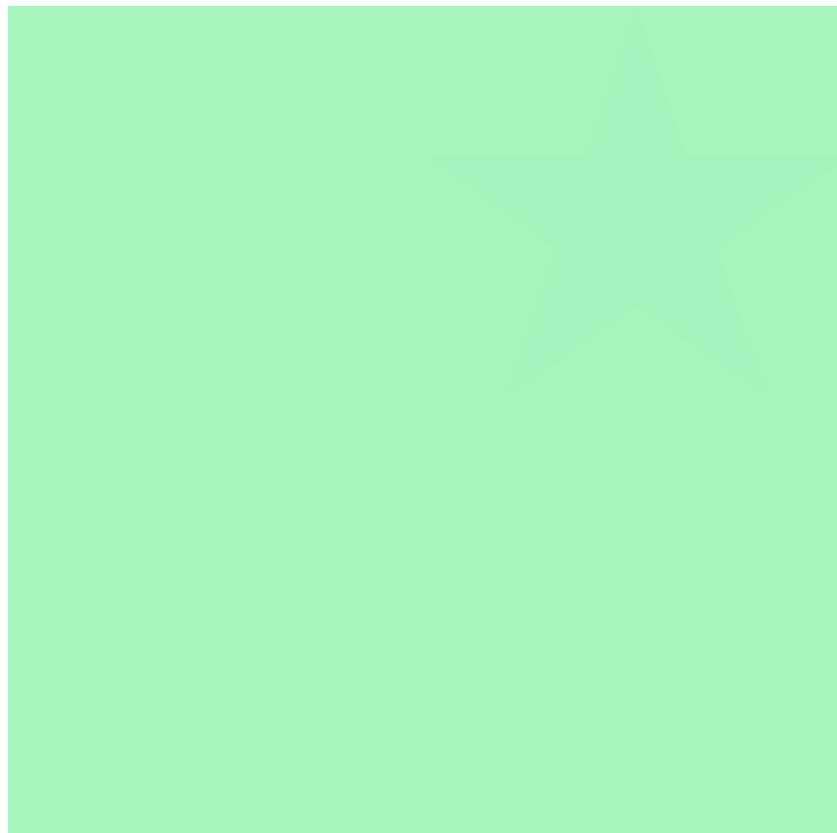
5 difference in G



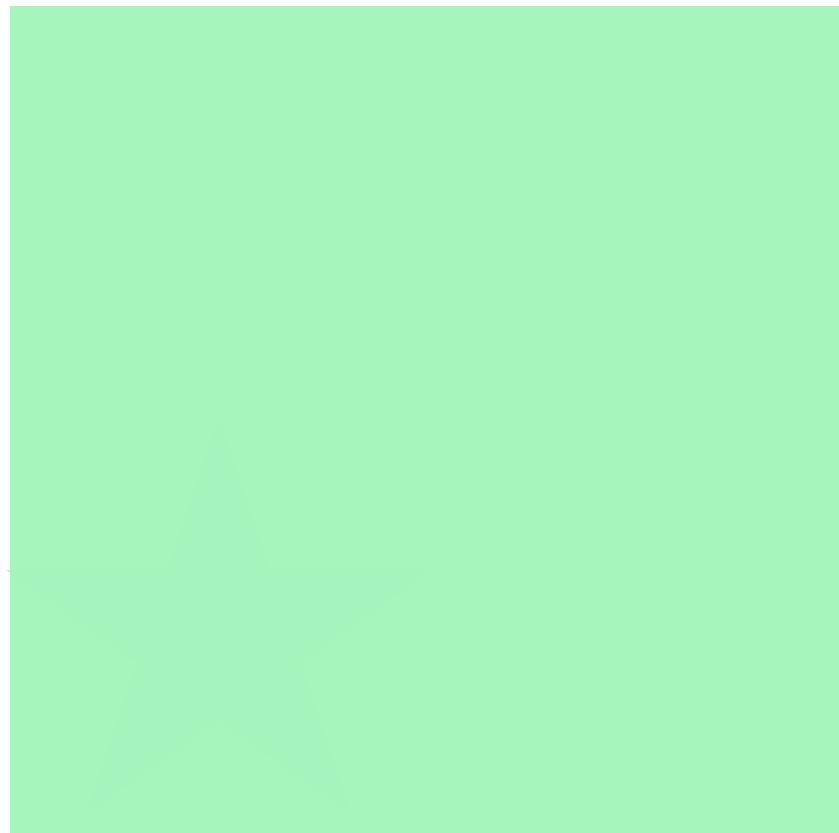
3 difference in G



2 difference in G



1 difference in G



5 difference in B



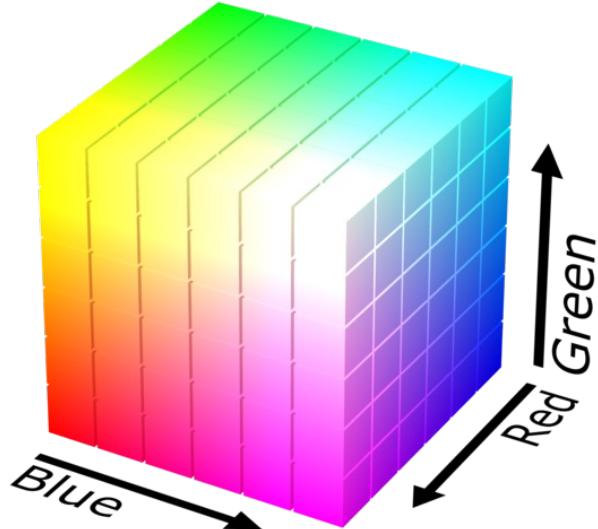
One Option: RGB

Pros

1. Simple
2. Common

Cons

1. Distances don't make sense
2. Correlated



R



G



B

RGB

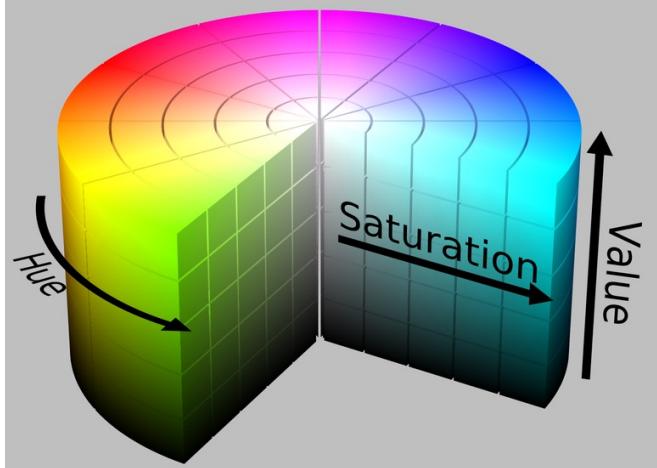


Photo credit: J. Hays

Another Option: HSV

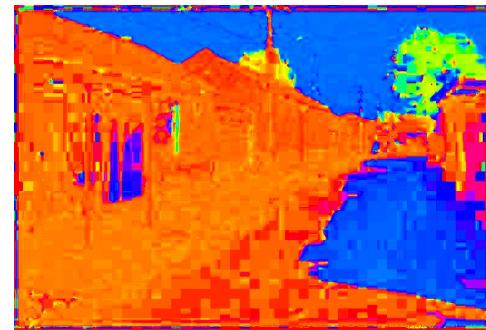
Pros

1. Intuitive for picking colors
2. Sort of common
3. Fast to convert



Cons

1. Perceptual Non-Linearity
2. Lack of Precision for Dark Colors



H
($S=1, V=1$)



S
($H=1, V=1$)



V
($H=1, S=0$)

HSV

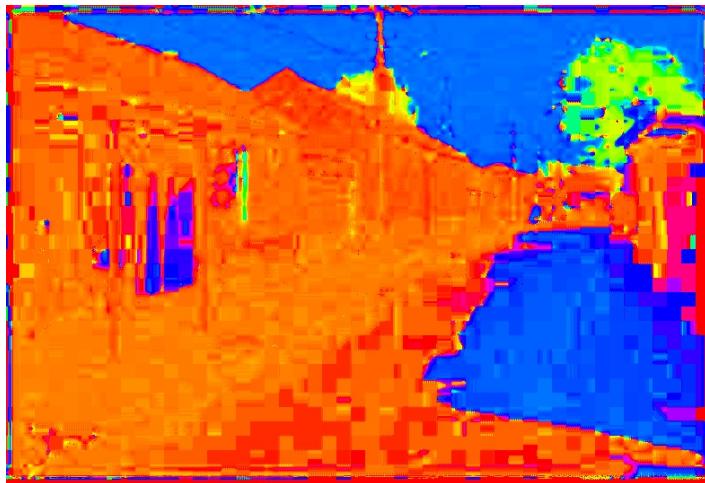


Photo credit: J. Hays

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Another Option: YCbCr/YUV

Pros

1. Great for transmission / compression

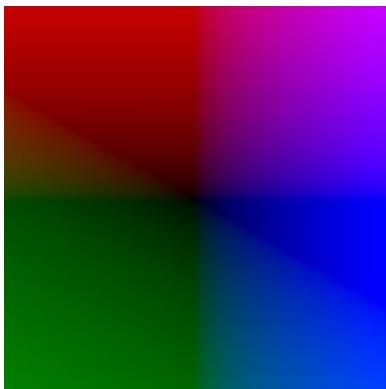
Cons

1. Not perceptual linear

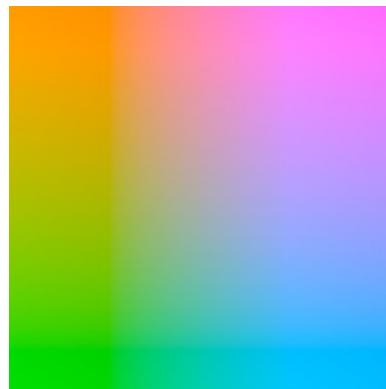


Y
(Cb=0.5,
Cr=0.5)

$Y = 0.1$



$Y = 0.5$



Cb
(Y=0.5,
Cr=0.5)



Cr
(Y=0.5,
Cb=0.5)

YCbCr



Photo credit: J. Hays

copyright 2000 phil@mit.edu

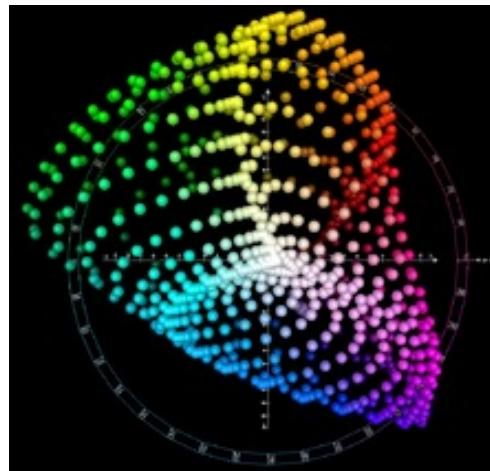
Another Option: Lab

Pros

1. Distances correspond with human judgment
2. Safe

Cons

1. Complex to calculate (don't write it yourself, lots of fp calculations)



L

(a=0,b=0)



a

(L=65,b=0)



b

(L=65,a=0)

Lab



Photo credit: J. Hays

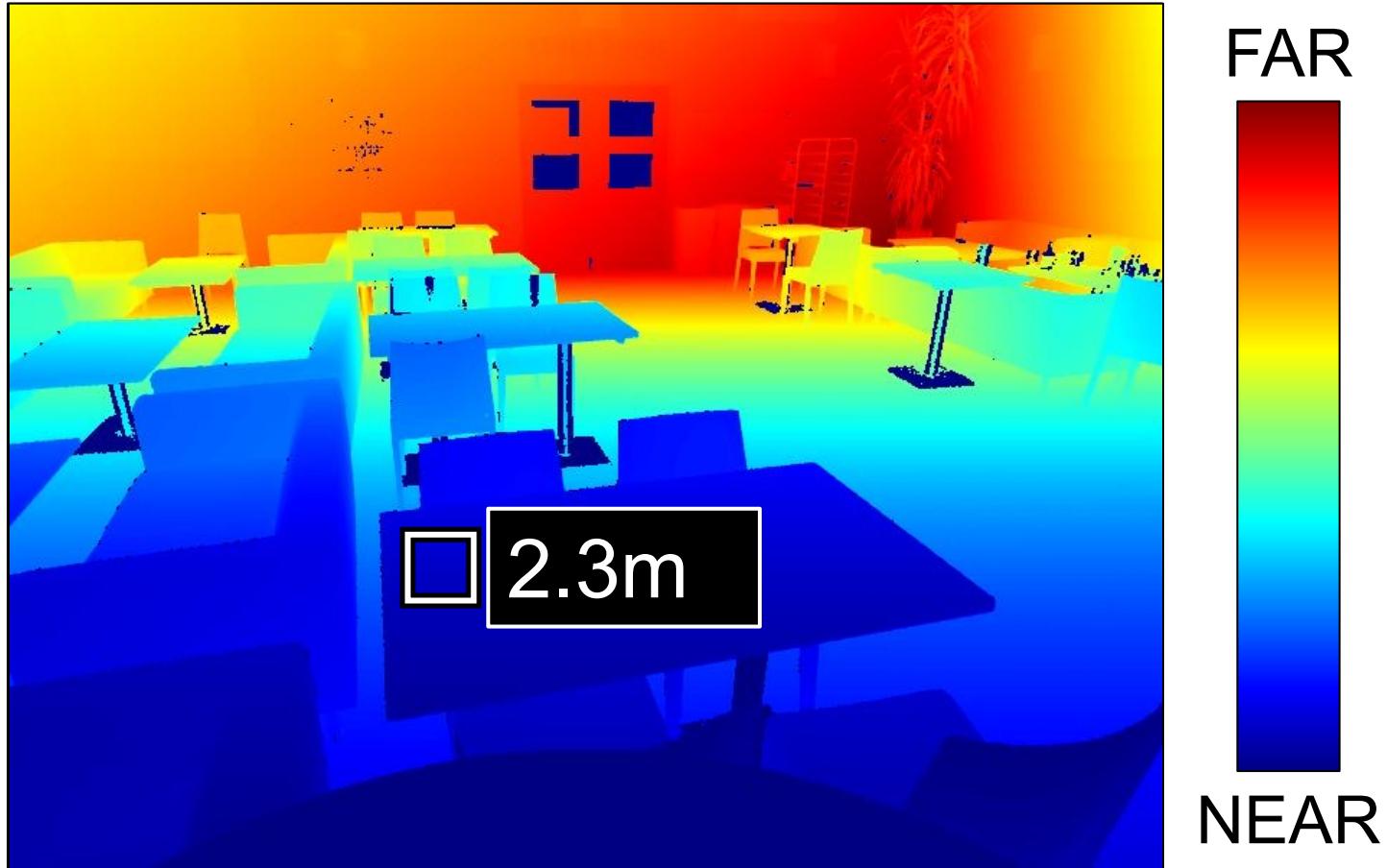
Why Are There So Many?

- Each serves different functions
 - RGB: sort of intuitive, standard, everywhere
 - HSV: good for picking, fast to compute
 - YCbCr/YUV: fast to compute, compresses well
 - Lab: the right(?) thing to do, but “slow” to compute
- Pick based on what you need and don’t sweat it: color really isn’t crucial

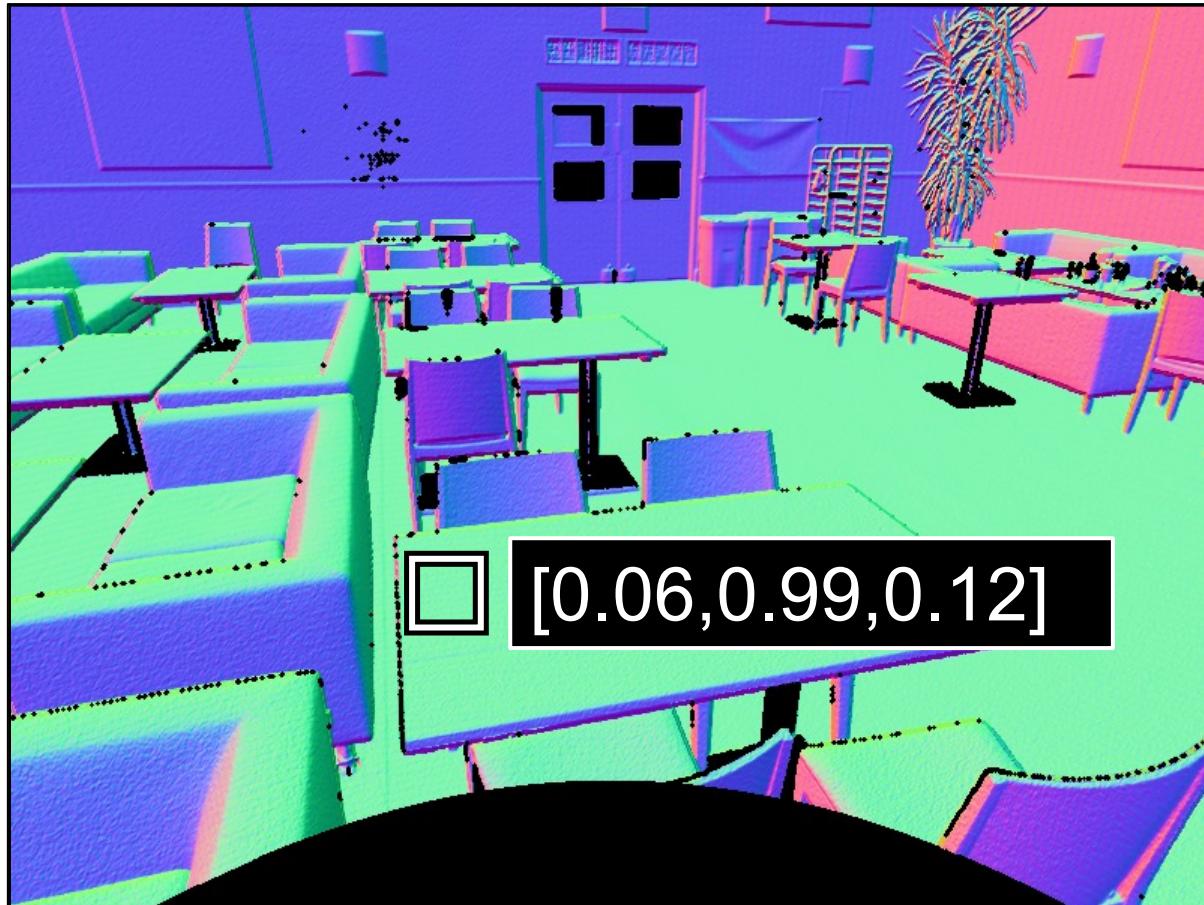
Only Images

- Almost all of this class is about ordinary RGB images because this has driven a lot of applications
- However, there are lots of other images

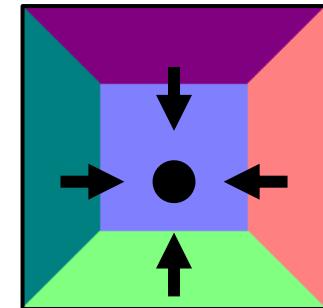
Depthmap



Surface Normals

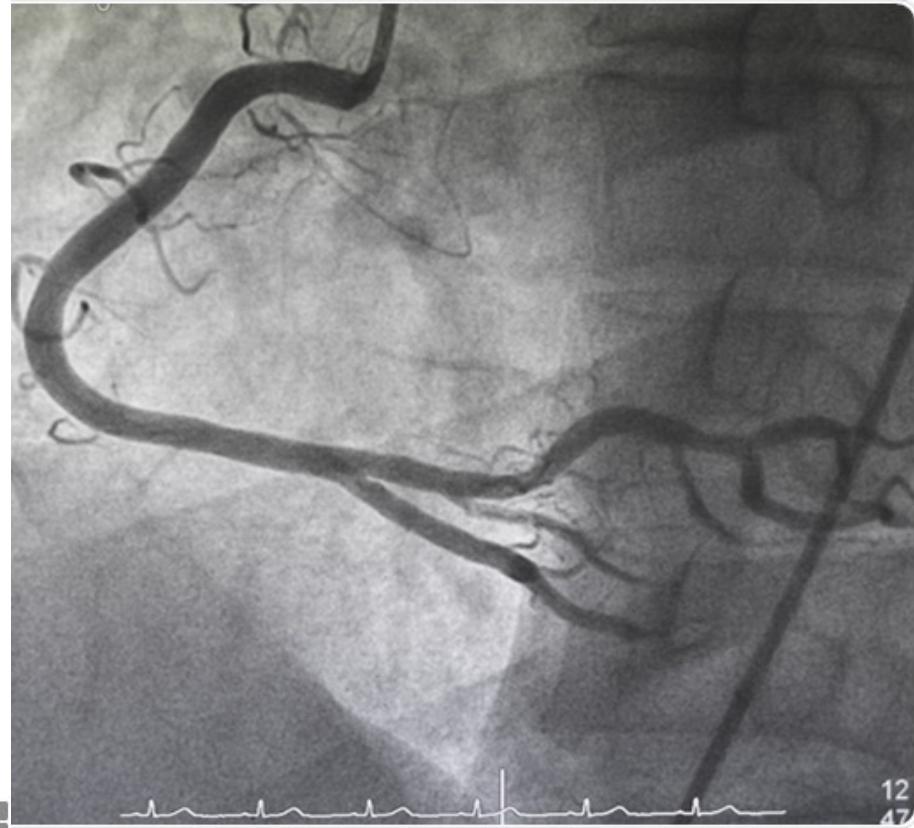
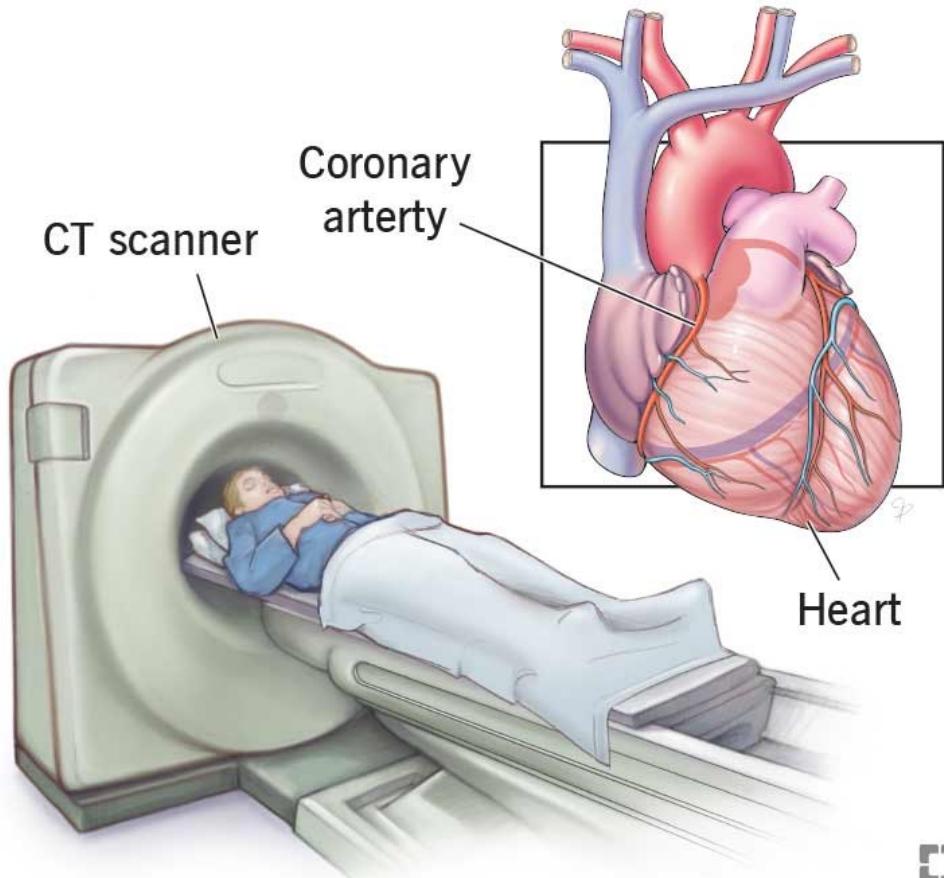


Room



Legend

CT Angiogram



Science Data

Magnetic Field in:

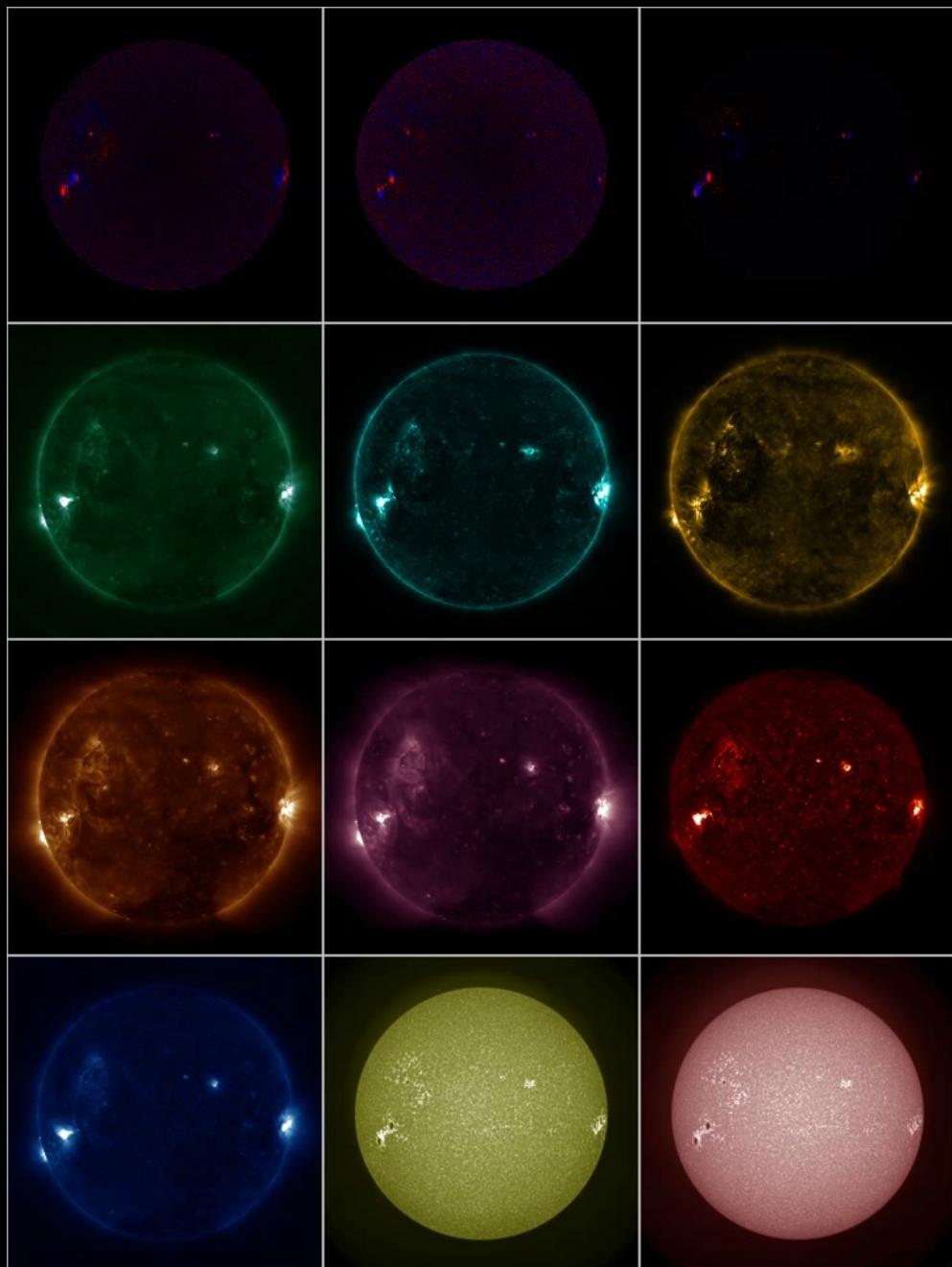
x, y, z

via polarized light

Light at 9 ~wavelengths:

9.4nm, 13.1nm, 17.1nm
19.3nm, 21.1nm, 30.4nm
33.5nm, 160nm, 170nm

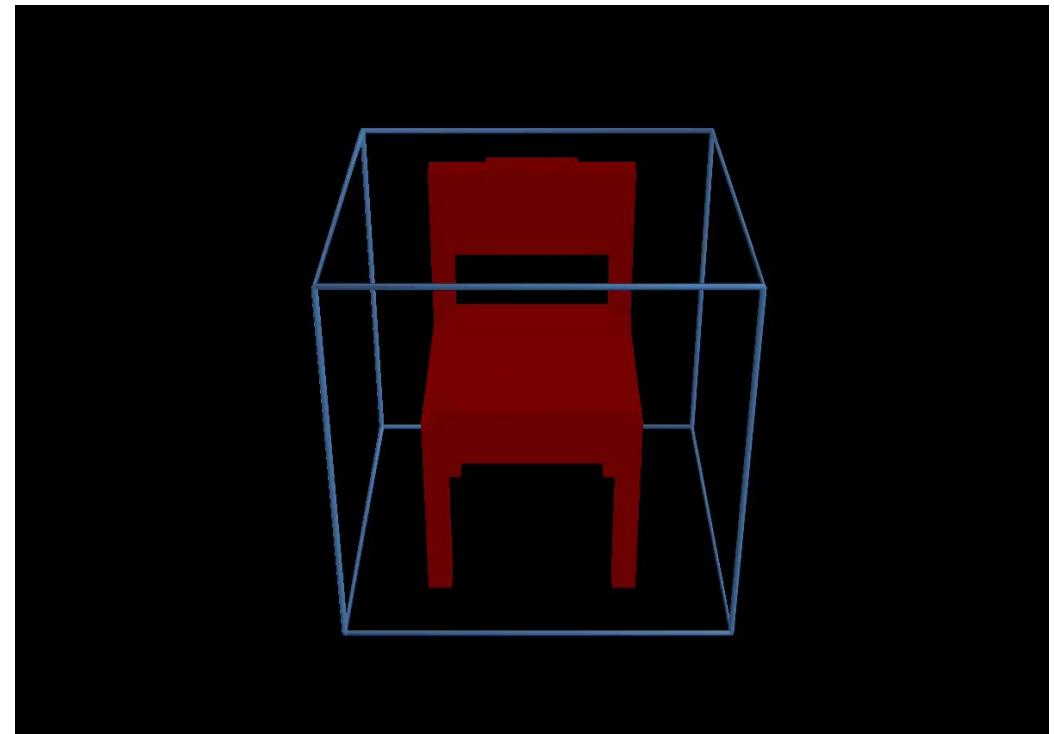
NASA Solar Dynamics
Observatory observing solar flare



Volumes

Volumes: images with more dimensions.

Emerge in 3D reconstruction,
medical imaging,
temporal data



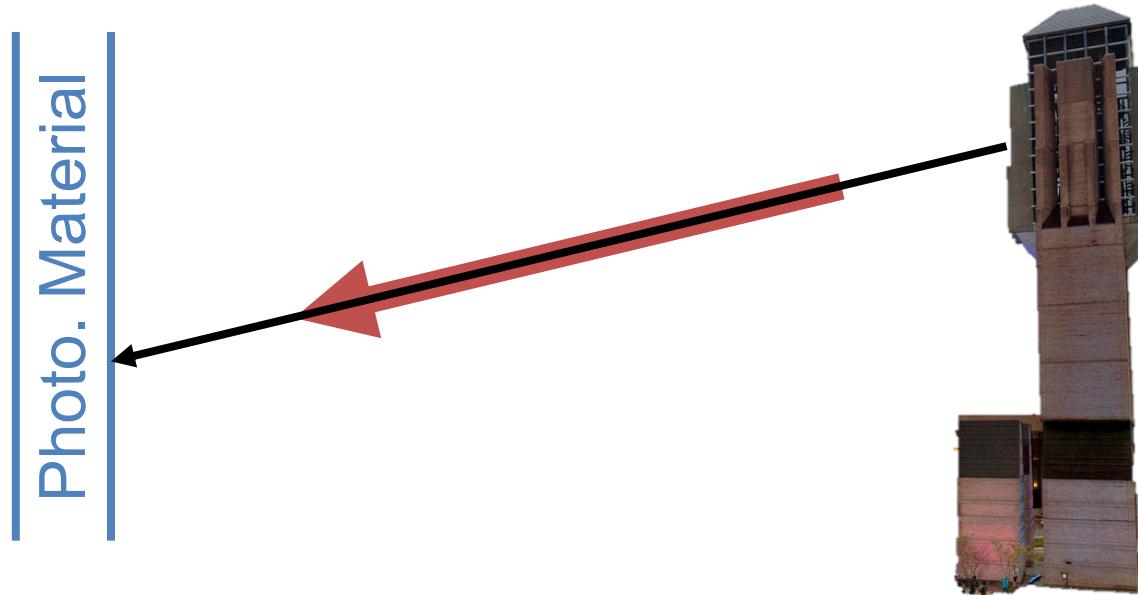
From: Girdhar et al., *Learning a predictable and generative vector representation for objects*.
ECCV 2016

Other Images

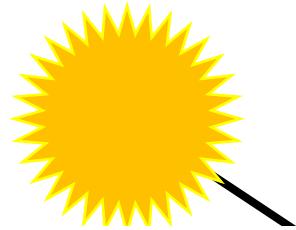
- A small part of computer vision in this class is really only for ordinary images
- The rest is easily generalized to other images
- Really transformative stuff will happen when good vision techniques get traction in other areas

So Far

How do we represent **light**
and its storage on **film**?

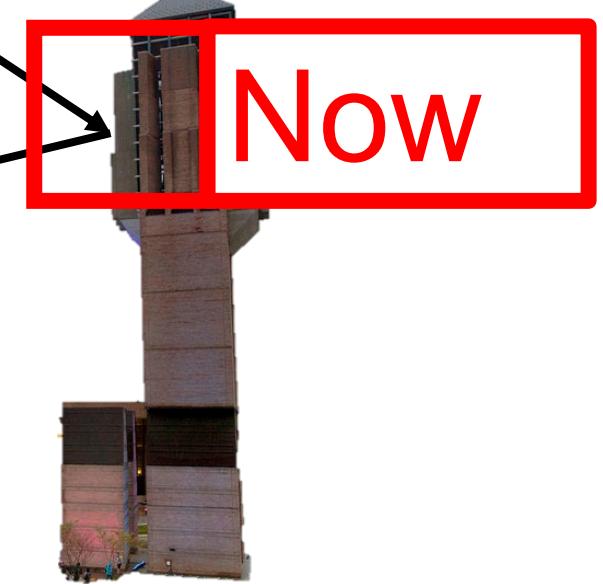


Now

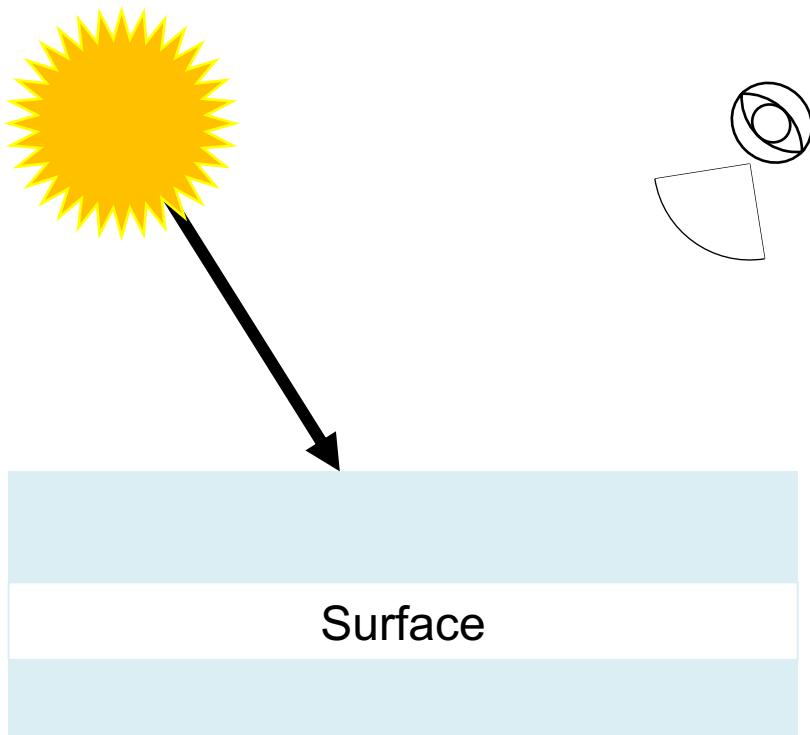


How does the scene
cause that **light?**

Photo. Material

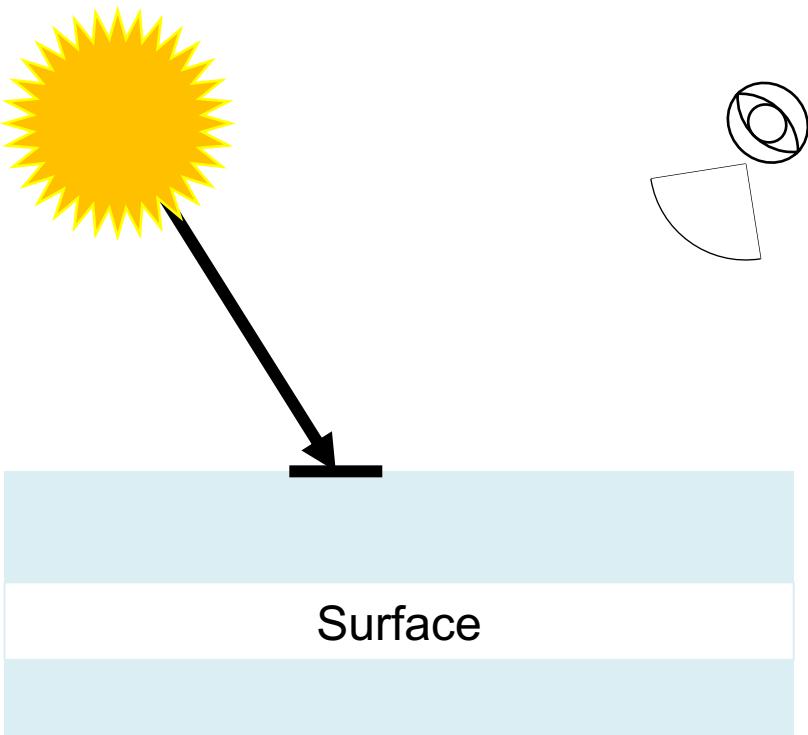


Light and Surfaces



What happens when
light hits a surface?

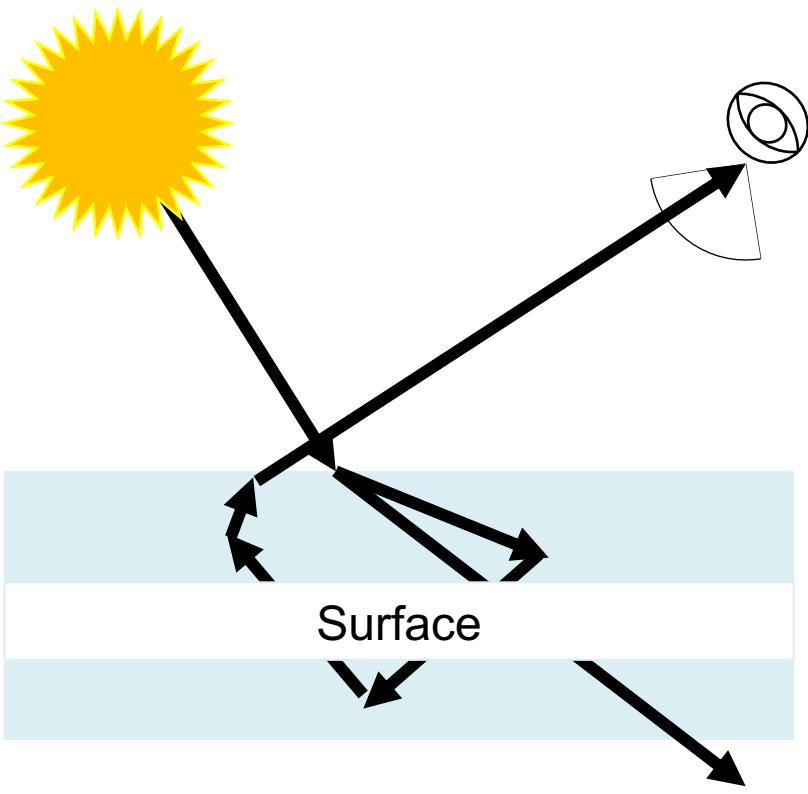
Light and Surfaces



What happens when light hits a surface?

- 1. Absorbed**
It's absorbed and converted into some other form of energy (e.g., a black shirt getting hot in the sun)

Light and Surfaces

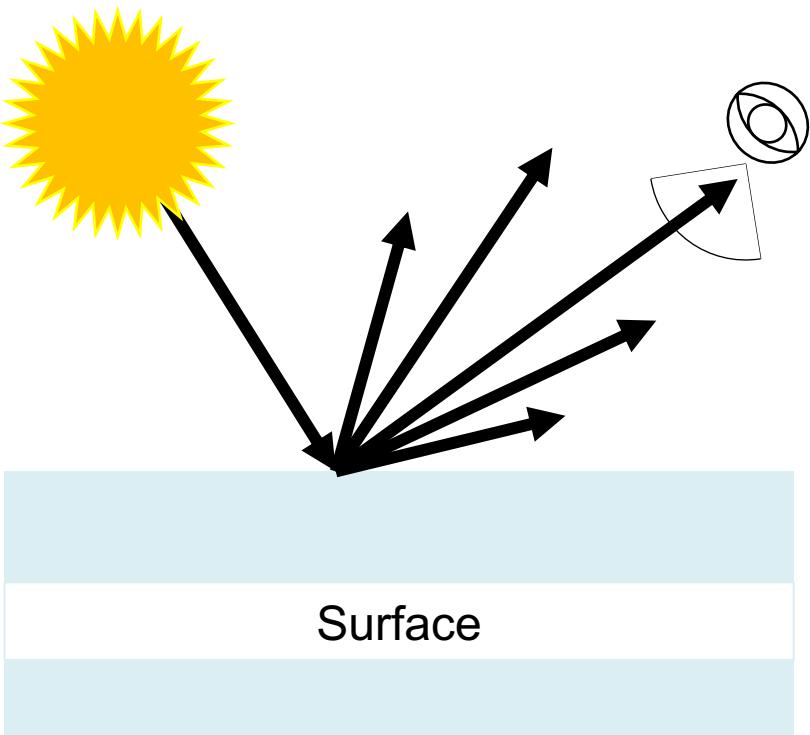


What happens when light hits a surface?

2. Transmitted

Possibly bouncing around before going through or out (e.g. lenses bend and go through, milk bounces around)

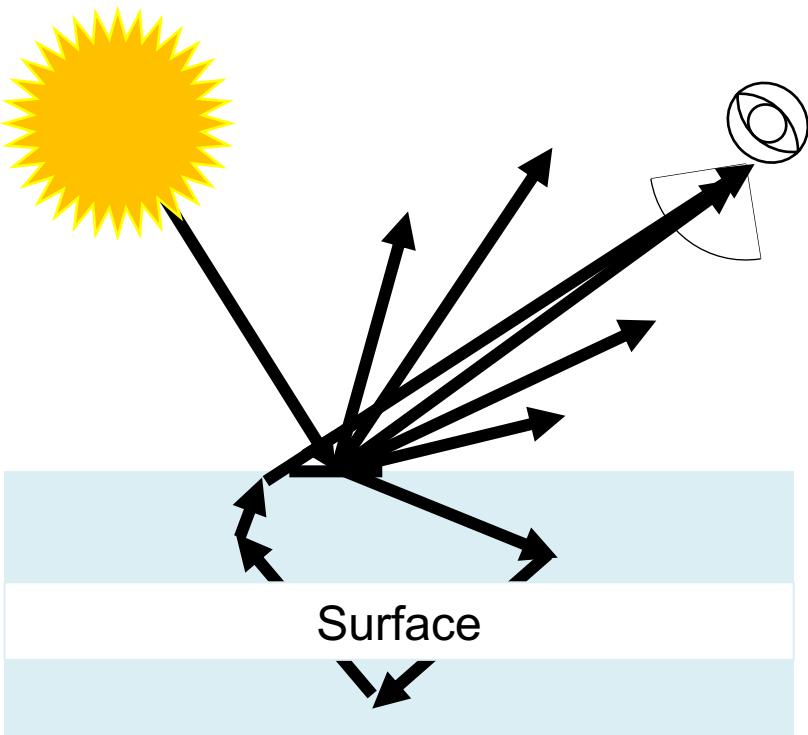
Light and Surfaces



What happens when light hits a surface?

- 3. Reflected**
It's reflected back, in one or more directions with varying amounts (e.g., mirror, or a white surface)

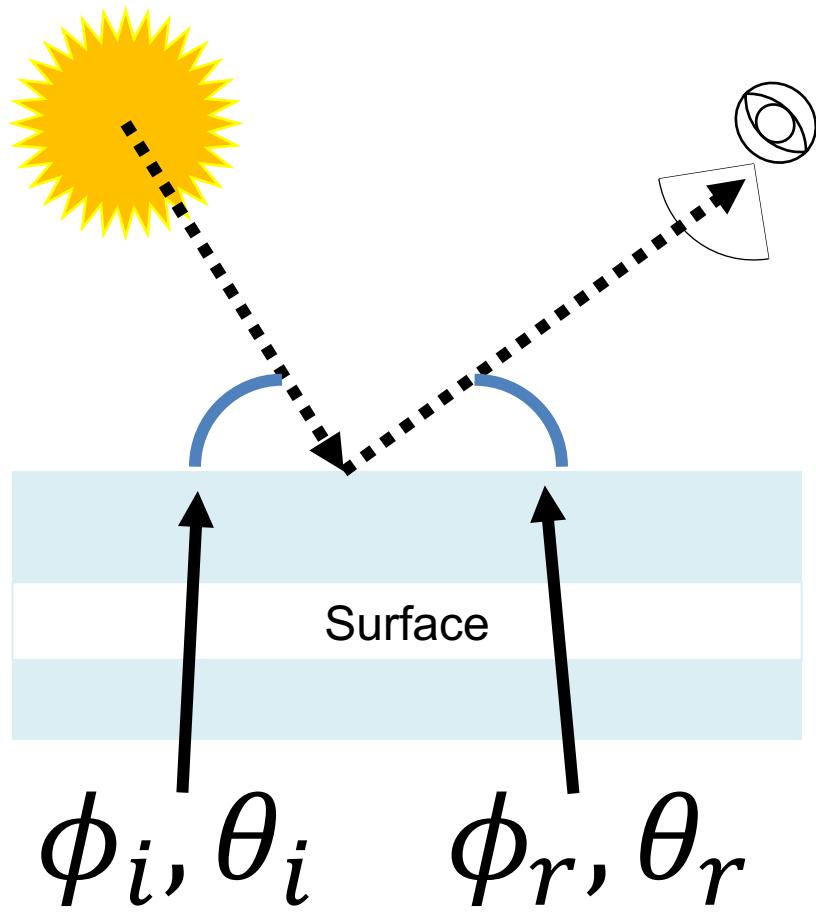
Light and Surfaces



What happens when light hits a surface?

4. Everything
All of the above! Real surfaces often have combinations of all of these options.

Modeling Light and Surfaces



Opaque Reflections

Bi-directional reflectance function (BRDF):
% reflected given
incident angle to light
reflected angle to the
viewer. Distribution!

Note: have not specified
form of function.

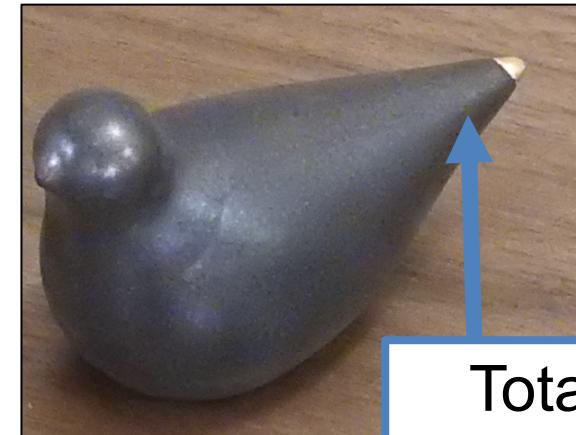
Specular and Diffuse Reflection

Same lighting, as close as possible camera settings, but different **location**



Specular and Diffuse Reflection

Diffuse Specular

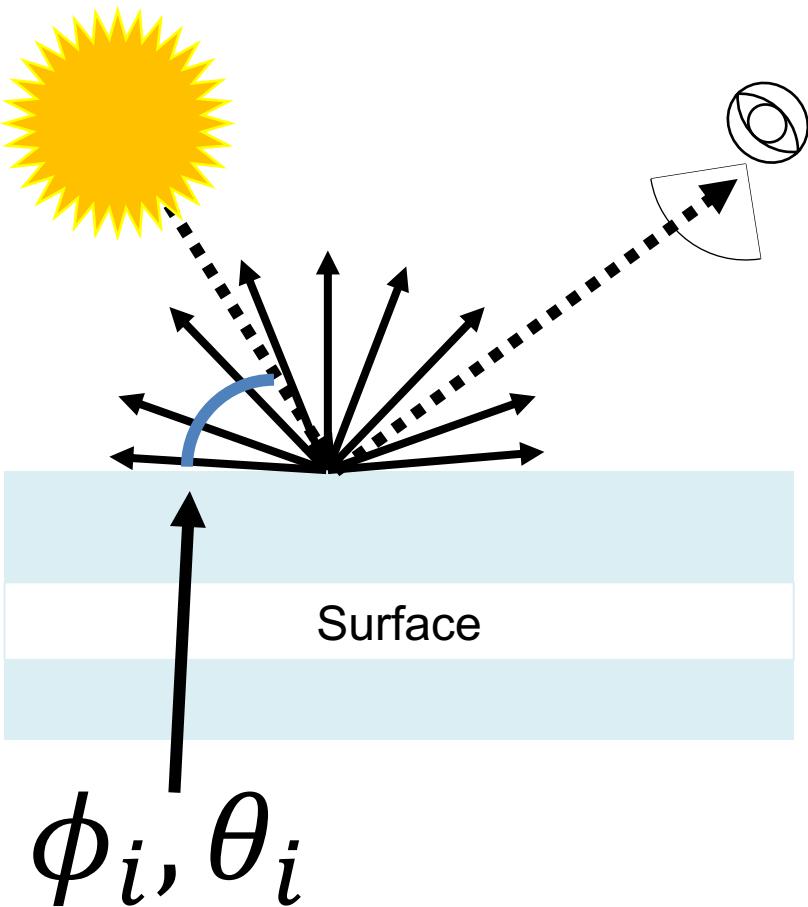


Basically
same



Totally
different

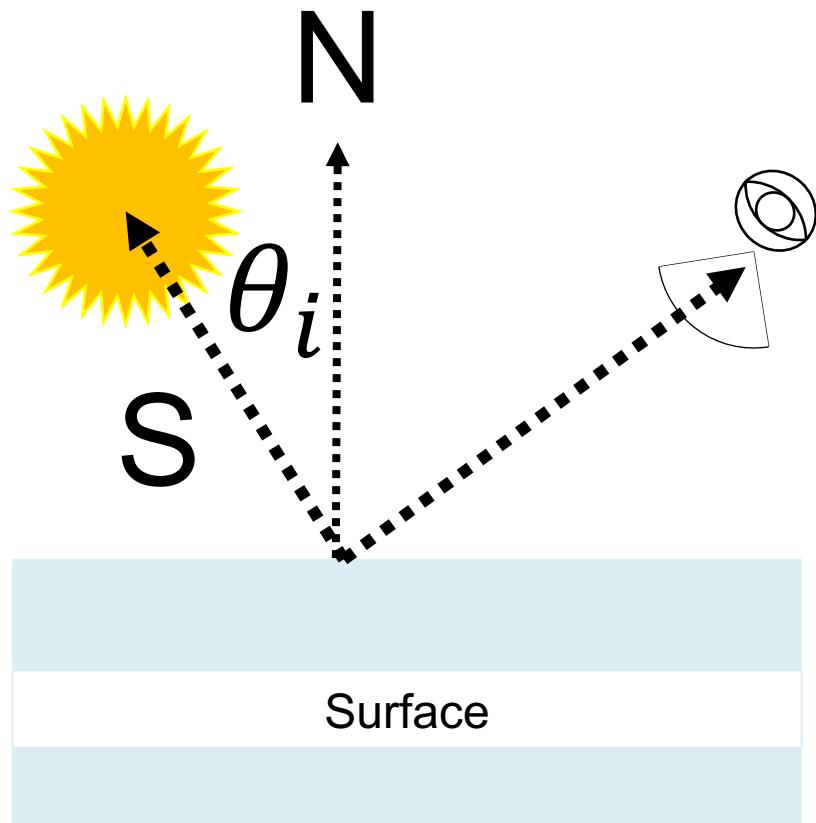
Diffuse Reflection



Lambertian Surface

Light depends **only** on orientation of surface
 ϕ_i, θ_i
to light. Result of random small facets. Looks identical at all views.

Diffuse Reflection



Lambert's Law

N : surface normal

S : source direction **and**
strength

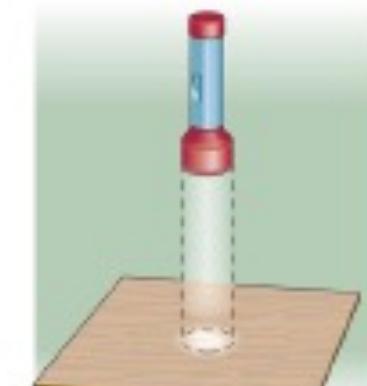
ρ : how much is reflected

$$B = \rho N \cdot S$$

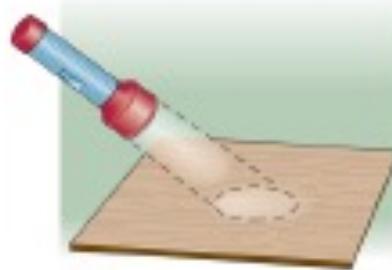
$$\underbrace{B}_{\text{Energy}} = \rho \|S\| \cos(\theta)$$

Lambert's Law and Seasons

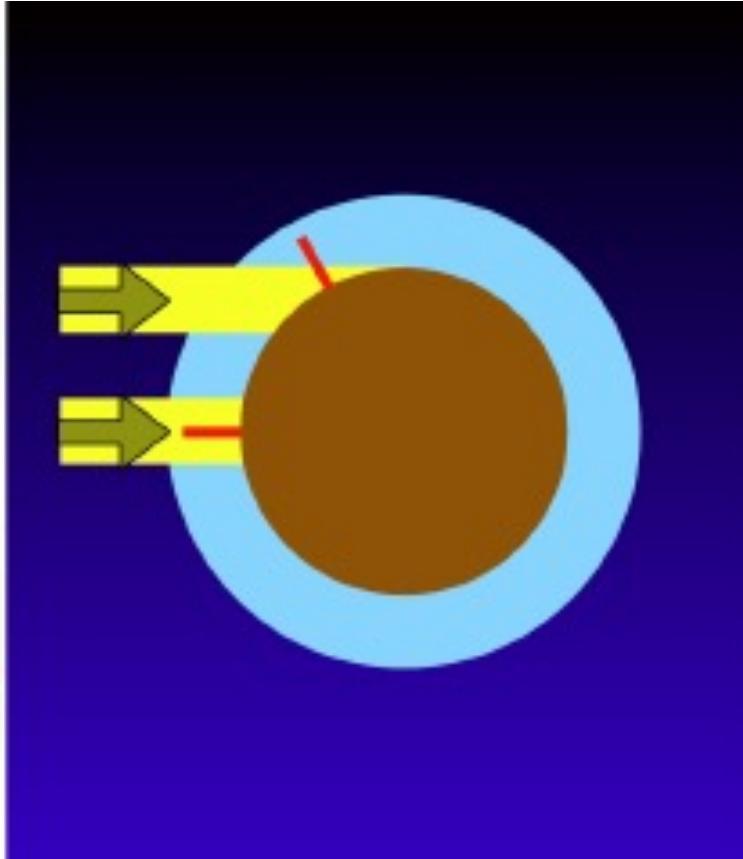
- Tilted light spreads over larger area: less energy per unit area

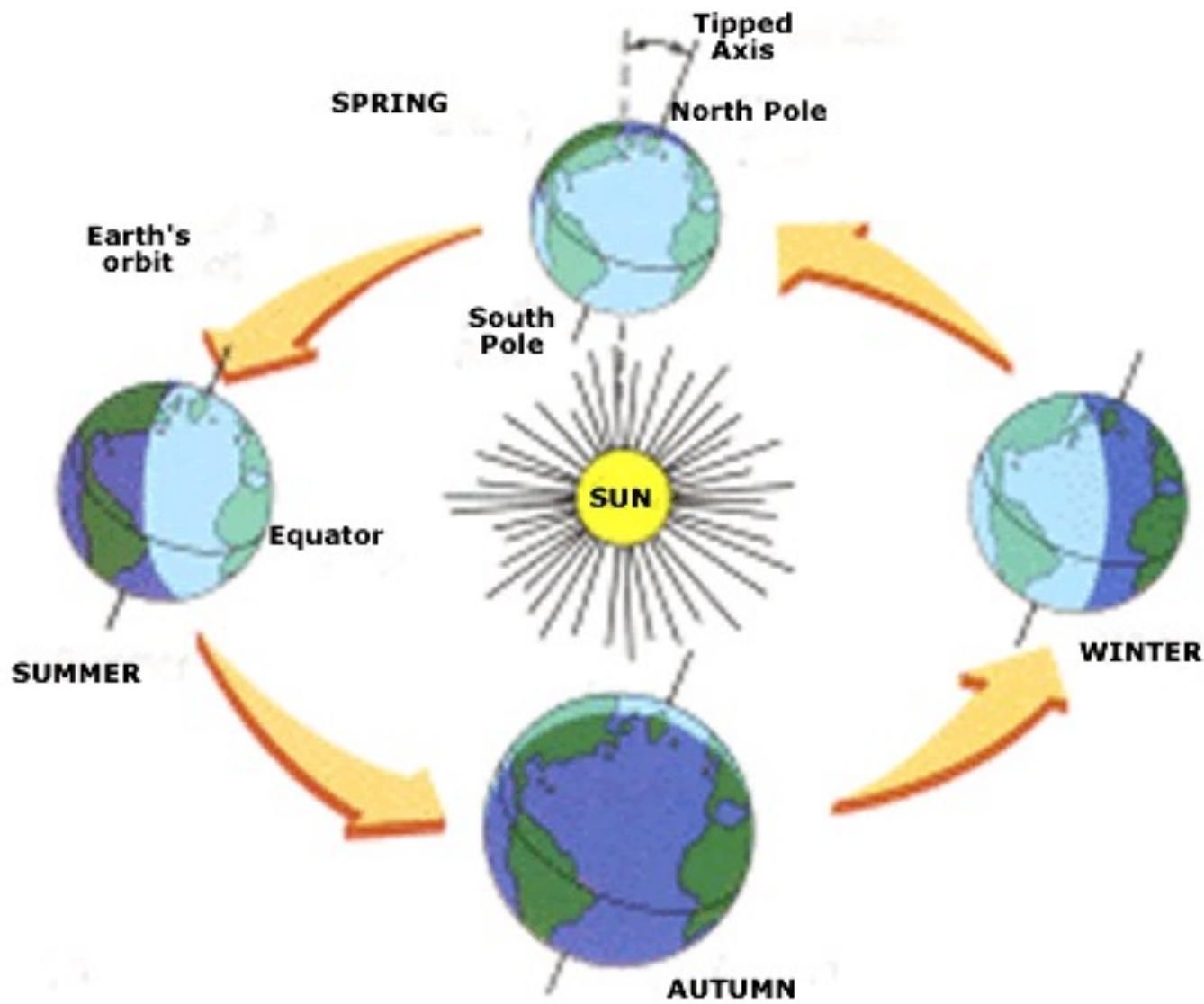


(a)

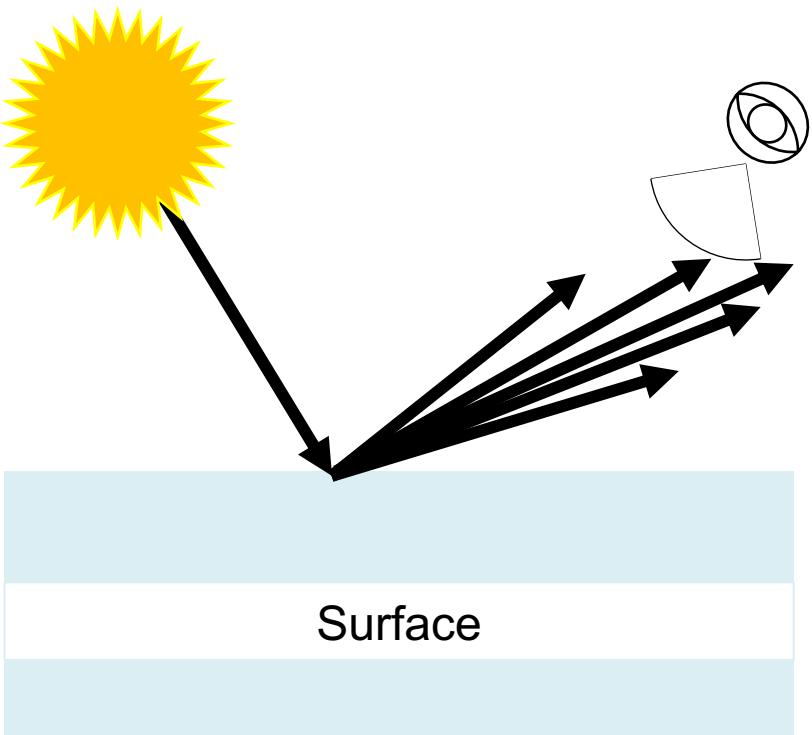


(b)





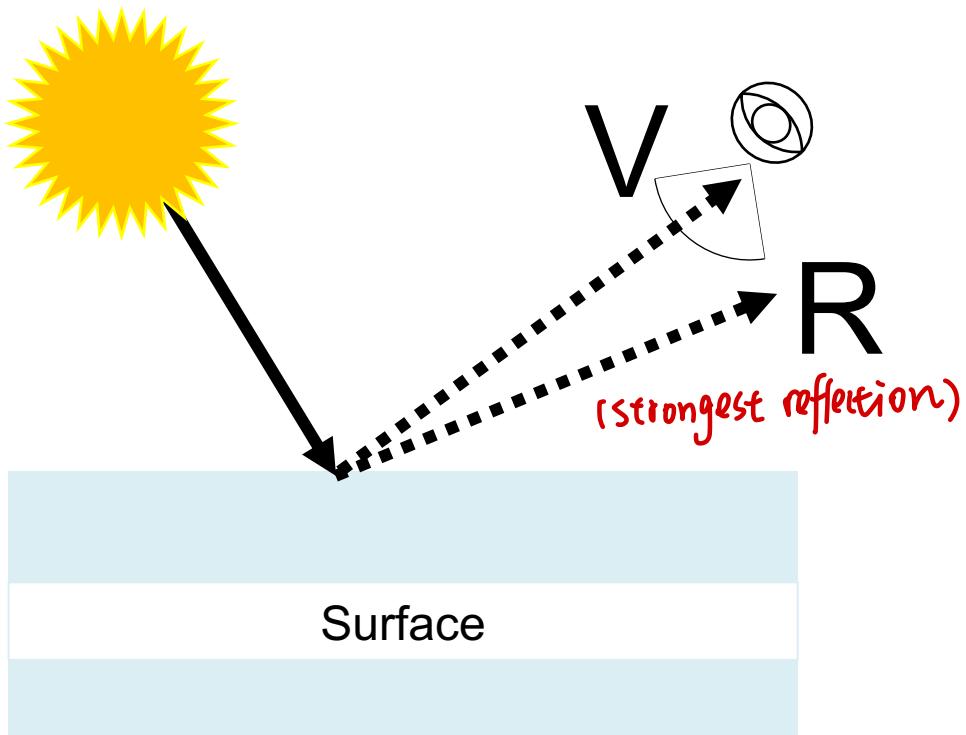
Specular Reflection



Specular Surface

Light reflected like a mirror, but spreads out in a “lobe” around the reflection ray

Specular Reflection



Phong Model

V: vector to viewer

R: reflection ray

α : shininess constant

$$B = (V^T R)^\alpha$$

BRDFs can be incredibly complicated...



What Can This Be Used For

Shape from Shading

Lambert's Law: for each i of K pixels,

$$B_i = \rho N_i \cdot S$$

Reflected Light (1 dim)
(scalar)

Surface Orientation (3? dim)

Illumination Global (3 dim)

Given: illumination & light & ρ , recover normals

Potential problems?

Shape From Shading

$$B_i = \rho \mathbf{N}_i \cdot \mathbf{S}$$

2D vector, Because it's a direction
and we have unit vector

1D, fixed 1D, fixed actually 2D unknown 3D, fixed

- System of K equations that's underdetermined (K equations, 2K unknowns)
- **Solution:** Add more equations that enforce smoothness or finding a single surface.

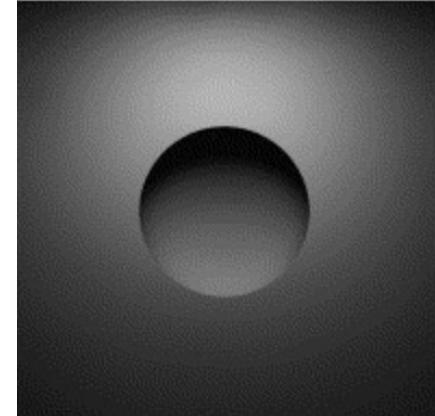
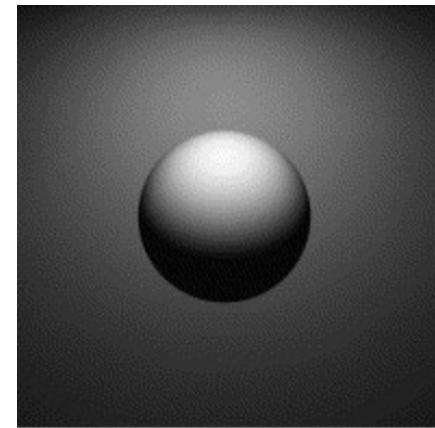
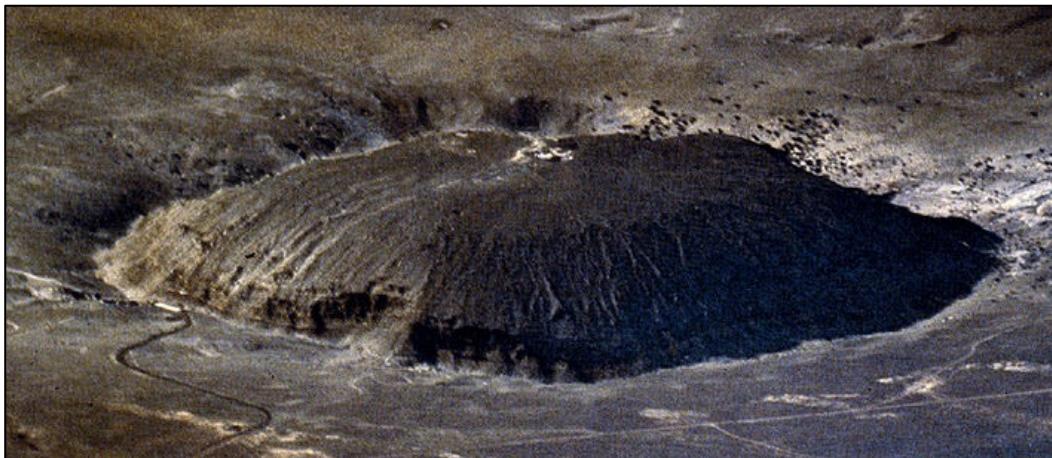
Realistic Shape From Shading

$$B_i = \rho N_i \cdot S$$

The diagram illustrates the components of the shading equation $B_i = \rho N_i \cdot S$. The term N_i is labeled "1D, fixed". The term S is labeled "1D unknown". The entire expression $\rho N_i \cdot S$ is labeled "2D unknown". The scalar ρ is labeled "3D, unknown". Arrows point from the labels to their respective parts in the equation.

- System of equations that's underdetermined (K equations, 3K+3 unknowns)
- **Solution:** need prior beliefs to disambiguate.

Ambiguity



Concave-Convex Ambiguity

Humans assume light from above (and the blueness also tells you distance)



Photo Credit: https://en.wikipedia.org/wiki/Meteor_Crater

Shape from Shading in Practice

<https://www.youtube.com/watch?v=4GiLAOtjHNo>